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A TEXT-BOOK OF

GEOLOGY

FOR USE IN
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AND FOR THE GENERAL READER

PART I

PHYSICAL GEOLOGY

BY

LOUIS V. PIRSSON

PROFESSOR OF PHYSICAL GEOLOGY IN THE SHEFFIELD SCIENTIFIC SCHOOL OF YALE UNIVERSITY

PART II

HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

PROFESSOR OF PALEONTOLOGY IN YALE UNIVERSITY AND OF HISTORICAL GEOLOGY IN THE SHEFFIELD SCIENTIFIC SCHOOL

PART II

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LOUIS V. PIRSSON and CHARLES SCHUCHERT

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PREFACE TO PART II

During the past ten years the writer has been giving a course in Historical Geology to undergraduate students in the Sheffield Scientific School of Yale University. From crude beginnings these lectures have gradually evolved into those here presented. At first they were based on Le Conte's widely known *Elements of Geology*, but as the writer's experience in teaching grew, he was led more and more away from that book. As the course developed, it was found desirable to introduce lectures showing the relationship of Historical Geology to Astronomy and Evolution, Biology and Oceanography, such as are given in Chapters XVII to XXVI. In addition it became apparent that most American students taking the first year's work in Geology, even those intending to devote their lives to the earth sciences, are often deficient in the elements of Botany and Zoölogy, and the existence of this unfortunate condition made it necessary for the writer to include also some discussion of the living world. As a result of this, the course became harder, but it gained in interest because of its wider scope, and, after all, Historical Geology is as much a biological science as it is a geological.

The material upon which the lectures are based has naturally been drawn from so many sources and has become so integral a part of the writer's fund of information that it is not easy to render complete acknowledgment. The well-known general treatises and works of Dana, Suess, Le Conte, Chamberlin and Salisbury, Scott, Geikie, Kayser, Walther, Neumayr, Credner, Jukes-Brown, and Lapparent are of course the main sources. Of great service have also been the more general works on paleontology of Zittel-Eastman, Osborn, Scott, and Williston; the zoölogies of Thomson, Parker and Haswell, and Weysse; the works on man by Sollas, Keith, and Huxley; the histories of Zittel, Geikie, and Merrill; the treatises on oceanography by Krümmel, Murray and Hjört, and Johnstone; astronomy as presented by Hale and Arrhenius; Clarke's work on geochemistry; and, for stratigraphy, Willis' great and comprehensive *Index*. Finally the wealth of fact and illustration in the works of the United States Geological Survey has been drawn upon freely.

The writer is much indebted to Doctor George Otis Smith, Director of the United States Geological Survey, and to Doctor Bailey Willis

for the great help given him in the preparation of the geological map of North America, which first appeared in Bowman's *Forest Physiography*. Other information and illustrations have been taken from the guides of the British Museum (Natural History), Koken's Führer to the University of Tübingen Museum, Fraas' Führer to the Stuttgart Museum, the state surveys of New York, Maryland, Ohio, Indiana, Minnesota, and New Jersey, and from other sources mentioned in the text and in the figure legends. Acknowledgment is due the Macmillan Company for permission to reproduce a number of illustrations from Osborn's *The Age of Mammals* and Scott's *A History of Land Mammals in the Western Hemisphere*, and the courtesy of the two authors in granting this privilege is also much appreciated.

The writer is grateful to his colleagues Professor Joseph Barrell for contributing Chapter XXV and several smaller sections and for reading and criticizing fourteen chapters, Professor Richard Swann Lull for allowing him to reprint Chapter XLVI, which first appeared in the *Yale Review*, and for aid in nine other chapters, and Professor Herbert E. Gregory for photographs. Thanks are also extended to his friends Doctor T. W. Stanton for aid on the Mesozoic chapters, Doctor George Grant MacCurdy for reading the one on man, Doctor John M. Clarke for help on the Devonian chapter and for photographs, and Doctor E. O. Ulrich for preparing the statement of the Ozarkian.

To Miss Clara Mae LeVene the author is especially thankful for the untiring editorial revision she has given the manuscript, and for seeing the book through the press.

The pen drawings have been made by Mr. William Baake and Doctor Stanley C. Ball.

CHARLES SCHUCHERT.

PEABODY MUSEUM OF YALE UNIVERSITY,
NEW HAVEN, CONN.,
July, 1915.

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PART II

HISTORICAL GEOLOGY

BY

CHARLES SCHUCHERT

CHAPTER XVII

MATTER AND ORGANISMS

Man, even though his body is large compared with the average size of living things, is after all but microscopic in nature. Finite, circumscribed, and weak though he is, he yet attempts to fathom the meaning of himself and likewise of all that is about him. He sees the moon, the sun, the myriads of stars in all the glistening splendor of their orderly array, and like the babe that reaches out and longs for the object appearing before his vision, so man through his mental eye, aided by the instruments of his own invention, wanders out into the vastness of space, ever observing, ever asking: What is the meaning of all this? Whence has it come? Though he stand face to face with the immutable laws of Nature and with Eternity itself, his questioning mind still seeks to overstep the boundaries of its finiteness and strives to comprehend the infinite.

Matter

Through our senses we perceive nature, — the material world and its extraordinary variety of manifestations: we feel, see, smell, taste, and hear it. Most of it is inert, and though we see that it undergoes change in part, it remains lifeless matter, the material of the universe. On the earth, however, we note the presence of material bodies which in their ceaseless chemical change manifest life and vitality, the " vital force " of the Greek philosophers, and these bodies are cognizant of the material world surrounding them. They live in it, absorb and change it into their own living bodies, and pass this property of their substance on to other entities, their descendants, which are more or less like themselves. The fundamental difference between the quick and the dead is that one is endowed with the quality of *irritability*, that is, the ability to undergo some slight internal change in response to equally small alterations in the environment; while the other is part of the lifeless world that only to a limited degree responds by chemical and physical change to external and internal agencies.

Inorganic Matter

The earth is composed of matter which science recognizes as *inorganic* and *organic*. The former is lifeless matter, much of which is in the crystal form, and hence it is sometimes referred to as the *Crystal Kingdom*. Organic matter, on the other hand, when alive manifests vitality, either in the form of single cells or in aggregates of cells, and thus is classified on the basis of its cell structure and mode of nourishment into the *Plant Kingdom* and the *Animal Kingdom*. In other words, the entities occurring in the inorganic world are in the crystalline form, or in fragmental or altered condition; while the bodies of living matter have their substance organized into a mechanism capable of response to external and internal agencies, and are hence called *organisms*.

Complexity of Matter. — Matter, whether of the earth or of the rest of the universe, is complex, divisible, resistant substance perceivable by our senses. It can be distorted, moved, broken, comminuted, or otherwise modified, but cannot be produced or destroyed. There are three states in which matter displays itself, the *solid*, the *liquid*, and the *gaseous*.

Matter commonly exists in more or less complex substances which can be broken up by chemical processes into at least eighty-four elements, without including the unstable and temporary forms involved in radioactive disintegration (*uranium* and *thorium*, see page 250). Each one of these elements is a kind of matter that cannot be separated into other kinds; they occur in the earth under ordinary conditions mostly as solids, more rarely as gases, and least often as liquids.

The elements which are of chief importance in forming the rock-shell of the earth have been mentioned on page 304. To them may be added hydrogen, carbon, and chlorine. In the envelope of water (the hydrosphere) the composition is: oxygen (85.8 per cent), hydrogen (10.7 per cent), chlorine (2.1 per cent), sodium (1.1 per cent), the remainder consisting of other elements in small quantities. In living substance, or the material of the biosphere (*bios* means life, therefore the sphere of plants and animals), there are always four elements present in large amounts, namely, carbon, hydrogen, oxygen, and nitrogen. Water in large proportion, usually 70 per cent or more, is essential to life, as are also certain inorganic salts, the most important of which are chloride of sodium and salts of phosphorus, calcium, magnesium, potassium, and iron.

The combination of these elements into a colloidal or jelly-like compound represents the chemical basis of living matter.

Nature of Inorganic Matter. — Inorganic matter is lifeless material in the simplest condition. In the crystalline form it begins in a nucleal molecule or particle; it enlarges by external addition or accretion alone, and there is hence no proper development, as the crystal is perfect, however minute; it ends in simply existing, and not in reproducing; and, being lifeless, it has no proper death or necessary dissolution. (Dana.) In other words, a crystal grows by the external addition of materials chemically the same, or of the same kind, as itself, arranged in layers, the body always retaining the same shape and constitution and never exhibiting internal circulation, motion, assimilation of food, internal growth, or reproduction of its own kind.

Organic Matter *

Organic matter in any form when alive is endowed with life, a condition that no one is able to explain completely. Active life, however, has been found to involve the following facts: The living organism *grows* at the expense of material different from itself, and this material is added within the body, while crystals grow by external accretion of substance. It is subject to continual chemical change, and yet has the power of retaining its integrity, of remaining more or less the same for prolonged periods. The physical basis of life invariably includes complex carbon compounds known as *proteids*.

A living creature is a more or less perfect *integrate* of organic corpuscles, that is, its parts are combined into a unit to make the individual, which has a *unified* behavior and gives effective response to external stimuli.

Manifestations of Organisms. — A living organism exhibits five inherent activities, — contractility, the power of movement, which is better developed in animals than in plants; irritability, the power of responding to stimulus in the wide sense, also more marked in animals; nutrition or utilization of food; respiration; and excretion, which is again greatest in animals — besides the periodic activities of growth and reproduction.

These manifestations of living matter are seen even in the simplest of plants and animals, where the individuals are microscopic in size and the unit is contained in a single cell (Fig. 312 *B*

* This section is largely taken, either verbatim or in modified form, from J. Arthur Thomson's *Outlines of Zoology*, 4th edition, 1906: 21–51.

and *C*). However, living matter is more commonly seen and comprehended when many cells live together and form the unit or individual, that is, in the plants and animals as usually understood (Fig. 312 *A*). All these forms are said to have a *body* con-

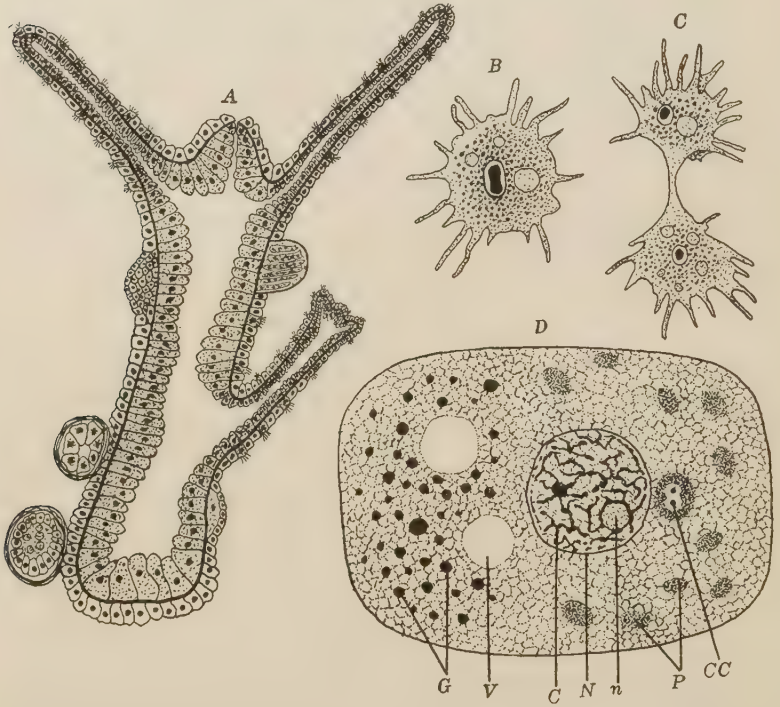


Fig. 312. — Cells and cell structure. *A*, a longitudinal section through the body and two tentacles of a fresh-water *Hydra*, to show the cell structure of a metazoan animal. Greatly magnified. *B*, a single-celled animal, *Amœba; C*, the same dividing into two individuals. Greatly magnified. *D*, diagram of cell structure. After Wilson. Very greatly magnified. *C*, chromosomes; *CC*, centrosome; *G*, granules; *N*, nucleus; *n*, nucleolus; *P*, plastids in the cytoplasm; *V*, vacuole.

sisting of unit masses or cells, which in the higher forms of plants run into countless numbers. It is impossible for these cells to remain the same, for as they increase in number they become diversely related to the outer world, to food, to one another, and so on. Division of labor, consequent on diversity of conditions, is thus established in the organism. In some cells one kind of activity predominates, in others a second, in still others a third, and this division of labor is associated with that complication of structure which is called *differentiation.*

Essential Differences between Plants and Animals. — The functions, cellular structure, and development in plants and animals are essentially alike, and there is no absolute distinction between them. These two groups are organisms differing in their totality of organization and in the detail of their functions; they have developed along two independent trunk lines since early in the earth's history.

When we contrast plants and animals it is easy to distinguish between such extremes as a fish and a flower, less easy to contrast a sponge and a mushroom, and well-nigh impossible to decide whether some very simple unicellular forms, which Haeckel called "Protists," have a predisposition toward plants or toward animals. We cannot do more than state average distinctions. The food which most plants absorb is cruder or chemically simpler than that which animals are able to utilize. Thus most plants derive the carbon they require from the carbon dioxide of the air, while only a few (green or chlorophyl-bearing) animals have this power; all the other plants and animals depend for their carbon supply on the sugar, starch, and fat already made by the green plants and animals. As regards nitrogen, most plants take this from nitrates and the like, absorbed along with water by the roots; whereas animals obtain their nitrogen from the complex proteids formed within other organisms. Most plants, therefore, feed at a lower chemical level than do animals, and it is characteristic of them that, in the reduction of carbon dioxide, and in the manufacture of starch and proteids, the kinetic energy of sunlight is transformed by the living matter into the potential chemical energy of complex foodstuffs. Animals, on the other hand, get their food ready-made; they take the pounds which plants have, as it were, accumulated in pence, and they spend them. For it is characteristic of animals that they convert the potential chemical energy of foodstuffs into the kinetic energy of locomotion and other activities. In short, the great distinction — an average one at best — is that most animals are more active than most plants.

Activity of Animals. — Most animals live an active life, in great part ruled by the two motives of love and hunger in their widest sense; they are busy finding food, avoiding enemies, wooing mates, making homes, and tending the young. These and other forms of activity depend upon internal changes within the body. Thus the movements of all but the very simplest animals are due to the activity of contractile parts known as muscles, which are controlled by nervous centers and by impulse-conducting fibers, and the energy involved in these movements, and in most other

vital activities, is supplied by the oxidation or combustion of the complex carbon compounds which form a substantial part of the various organs.

The work done means expenditure of energy, and is followed by exhaustion (muscular, nervous, etc.), so that the necessity for fresh supplies of energy is obvious. This recuperation is obtained through food, but before this can restore the exhausted parts to their normal state, or keep them from becoming, in any marked degree, exhausted, it must be rendered soluble, diffused throughout the body, and so chemically altered that it is readily incorporated into the animal's substance. In other words, it has to be digested. A fresh supply of oxygen and a removal of waste are also obviously essential to continued activity.

We may say, then, that there are *two master activities* in the animal body, those of muscular and those of nervous parts. To these the other internal activities are subsidiary conditions, turning food into blood and blood into tissues, and thus repairing the waste of matter and energy, keeping up the supply of oxygen, sifting out and removing waste products, and so on.

Growth and Reproduction. — Besides the more or less constantly recurrent activities or functions, there are the processes of growth and reproduction. When income exceeds expenditure in a young animal, growth goes on, and the inherited qualities of the organism are more and more perfectly developed. At the limit of growth, when the animal has reached *maturity*, it normally reproduces, that is to say, liberates either parts of itself or special germ-cells which give rise to new individuals.

Protoplasm. — Protoplasm is the genuinely living matter, or, as Huxley happily expressed it in 1870, it is "the physical basis of life." It cannot be clearly stated what protoplasm is. Professor E. B. Wilson in 1896 said: "The ultimate basis of living matter is not a single chemical substance, but a mixture of many substances that are self-propagating without loss of their specific character." Thomson states: "Protoplasm is a marvellous form of matter in motion, or a subtle kind of motion of which we can form only a very vague conception."

Cells. — All complex organisms are made up of organs and these are composed of tissues that are contractile, nervous, glandular, etc. In turn the tissues are made up of cells, so that all organisms have a *cellular structure* and a cellular origin (Fig. 312 *A–D*). The simplest organisms are unicellular and the entire life process goes on in such single cells, each a unit mass of living matter; as

such all plants and animals begin. In the great majority of organisms, however, the body is made up of hundreds upon hundreds of cells combined into tissues and organs.

A cell is a unit mass of living matter, usually with a nucleus. Most cells are too small to be distinguished except through lenses; many single-celled animals (Protozoa) are just visible to our unaided eyes. The largest animal cells are eggs distended with yolk.

Plant Cells and Animal Cells. — In a general way it may be said that the cells of plants have firm, more or less thick walls enclosing protoplasm, with granules (chloroplasts) of green coloring matter (chlorophyl). This stiffness of wall structure isolates the living substance, and consequently independence of action, that is, movement, in plants, as compared with that in animals, is diminished. By means of the green coloring matter, plants have the power of producing their own nutritive substances from certain constituents of the air and water and from the salts contained in the soil, and they are thus able to exist independently; while animals are dependent for their nourishment, and so for their very existence, on plants. Plants are therefore the primary magazines of food.

Origin of Life

What is Life? — Everyone knows, or thinks he knows, what life is; at least, we are all acquainted with its ordinary, obvious manifestations. It would, therefore, seem that it should not be difficult to find an exact definition. The quest has nevertheless baffled the most acute thinkers.

Life has not been demonstrated to be independent of matter; it is always associated with very complex carbon compounds, and is always derived with change from previous life. For twenty centuries philosophers held that life was being constantly and spontaneously generated (*spontaneous generation*) out of inorganic matter, or that it arose out of dead animals, or developed as worms in the intestines of animals. All of the stated cases of spontaneous generation, however, have been proved to arise in invisible organic germs floating in the air and falling into water or other environment necessary to growth and development. In the case of dead bodies giving rise to new and very different life, this is now seen to be due to insects depositing their eggs in the carcasses of animals, where they feed and develop into maggots and other larval forms. Intestinal worms arise in eggs swallowed by the host.

On the basis of established facts in Biology it can be said that we know nothing of a positive nature as to the origin of life. It is the greatest of the unsolved problems confronting man.

Schäfer gives his opinion thus in 1912:

"Looking at the evolution of living matter by the light which is shed upon it from the study of the evolution of matter in general, we are led to regard it as having been produced, not by a sudden alteration, whether exerted by natural or supernatural agency, but by a gradual process of change from material which was lifeless, through material on the borderland between inanimate and animate, to material which has all the characteristics to which we attach the term 'life.'"

On the other hand, it is now established that there is no sharp boundary between inorganic and organic chemistry, as organic compounds are produced from inorganic substances. Organic chemistry has become the chemistry of carbon compounds, but none of these compounds so far made evinces life, growth, or reproduction.

Ancient Origin of Life. — Life has been propagating life with change (evolution) probably ever since the earth has had a hydrosphere and atmosphere. How, where, and when it began is geologically unknown, and the only help the paleontologist can give is the proof that life has been on the earth countless ages. We note its presence indirectly for eon upon eon through its chemical action upon the elemental substances, as shown in the accumulation of carbonaceous deposits (black shales, graphite), limestones and dolomites, and iron ores, all of which in the earliest records of the earth are, however, without visible fossils. For the first time in the Proterozoic (Chapter XXIX) we meet with the actual remains of organisms, lime-secreting sea-weeds and annelids. This evidence seems not to be in accord with the theory derived from a study of living organisms, which demands that the earliest forms of life should be the most lowly kinds, for these fossils are highly organized. However, these occurrences in the ancient rocks do not disprove the theory that life began in simple microcosms, rather are they indirect evidence confirming the theory. The primordial life was in all probability exceedingly minute and too perishable to be preserved as fossils; it attained maturity, propagated, and vanished with astonishing rapidity. Slowly in the course of the eons the individual cells attained to larger growth and greater complexity; some congregated and lived attached to one another as a colony, but still kept their individual independence, and this neighborly association led to division of labor among the cells, to the formation of localized functions, and finally to the development of tissues

and organs. Thus was developed a "body," a greater and better organic workshop and a resistant mass wherein was also stored a greater amount of food, all of which finally led to longevity.

Classification of Organisms

Basis of Classification. — It is instinctive with humanity to group things of a kind together; for instance, animals that feed on plants we speak of as plant-feeders (herbivorous), those which seek flesh for food we know as flesh-feeders (carnivorous). However, a natural classification is not based on mere superficial resemblances, as is sometimes thought by people who are not naturalists, and who speak of all animals that inhabit the ocean as fishes, a fact which has led to the inclusion of the whales under this term, although they are truly warm-blooded mammals and nurse their young with milk like those living on the land. Systematic biologists, that is, students of organic relationship, are careful to select, as a basis for grouping, such characters as have a fundamental significance leading to the discovery of natural descent, organisms with the same structure and related genealogy being classed together. This means not only that the organisms so grouped must be structurally alike at maturity, but also that they must have a very similar life development from the egg onward. The study of the stages of growth in the individual is the science of *Ontogeny*, which includes *Embryology*. This study is also applicable to the fossils and we can thus trace more or less imperfectly the history of living things back into their geologic ancestry, and the process may be continued into the most remote times. Therefore the botanist and the zoölogist must coöperate with the paleontologist in the grouping of organisms into natural classifications. In addition, the paleontologist notes the appearance of the organisms in the stratified rocks, this time sequence being called *chronogenesis*. Therefore the named divisions in any scheme of organic classification are finally based on organic structure, ontogeny, phylogeny, and chronogenesis.

Grouping of Organisms. — All organisms are divided into the plant kingdom, or *Plantæ*, and the animal kingdom, or *Animalia*. These are the largest divisions, and while all organisms are referred to one or the other of them, in reality a sharp boundary line between plants and animals first becomes possible when they exhibit a complicated structure. This, however, is in accordance with the theory of evolution, which holds that the higher organisms have

been evolved from the lower. In common practice there is no difficulty in distinguishing plants from animals.

The kingdoms of plants and animals are each again divisible, like the parts of a tree, into other and smaller groups, of which there are many categories. In this place only the larger ones will be considered. After kingdoms come the great trunk lines, or stems, of organic structures, each one of which is known as a phylum (plural phyla), and so the grouping continues into smaller and smaller divisions until finally the individual is catalogued, the unit and basis of all classifications. For easy reference these various divisions may be grouped as in the following example:

Kingdom (Animalia);
Phylum (Chordata, or vertebrate animals);
Class (Mammalia, or mammals);
Order (Carnivora, or carnivorous animals);
Family (Felidæ, the cats);
Genus (*Felis*, a member of the cat family);
Species (*Felis tigris*, the tiger);
Individual.

Names of Organisms. — It is the ambition of naturalists to name all plants and animals, living and fossil, and according to the *rules of nomenclature* regulating this proceeding, each species, that is, a group of individuals which resemble one another in certain characters, is to have two names. The first one is called the generic name and is taken from the Greek or Latin language; for instance, the genus *Elephas* from the Greek *elephas*, elephant, and the genus *Felis* from the Latin *felis*, cat. A genus may contain but a single species or it may have several or even many, but in all cases where the species are grouped under the same generic name, it means that all have in common the structural characters on which the genus is founded. The specific name is taken from the Latin language or is a Latinized form of a word from another tongue; for instance, the common house cat is called *Felis domestica*, the lion is *Felis leo*, the African elephant is known as *Elephas africanus*, and the Indian form as *Elephas indicus*. This double naming is called *binomial nomenclature* and was established by Linnæus in the year 1735.

In America it is the custom to write the generic name with an initial capital letter and the specific and varietal names, of whatever significance, with an initial small letter. Both names are written in italics.

Divisions of the Plant Kingdom. — The plant kingdom may be divided into two subkingdoms, the *Cryptogams* and *Phanerogams*. The former, of which mushrooms and ferns may be cited as examples, include an extraordinary variety of the most different plant forms, extending from unicellular organisms to plants exhibiting division (segmentation) into stem, leaf, and root. Cryptogams propagate by unicellular spores, which they set free. They include three phyla (or stems) of which only the Pteridophyta (ferns, rushes, and club mosses) will be considered in this book. The Phanerogams have seeds, multicellular bodies in which is included the embryo of a plant. In other words, Cryptogams are "spore plants," while Phanerogams are "seed plants." The latter include the most highly developed forms, such as our common garden plants, and are also often called "flowering plants," because all of them have flowers, while the Cryptogams may or may not bear flowers.

Divisions of the Animal Kingdom. — The animal kingdom is divided into two subkingdoms, *Protozoa* and *Metazoa*. In the former the individual or unit animal consists of a single cell, that may lead a free life independent of its associates, or with them may combine into colonies. In the colonial form, however, each cell is a complete individual and there is as a rule no division of labor among the members of the colony. In the Metazoa, or higher animals, as they are usually called, while the cells are also grouped into tissues and organs, there is always a division of labor among them. In other words, the Protozoa are usually very simple microscopic animals, almost unknown except to scientists, while the Metazoa are multicellular animals, varying greatly in size and of different degrees of complexity, and are more or less known to everyone.

The subkingdom Metazoa is commonly divided into the Chordata or *vertebrates* and Invertebrata or *invertebrates*. The former are the backboned animals, or those with internal bony skeletons, such as the dogs, cattle, birds, fish, and the like; while the latter are the backboneless animals such as the insects, worms, shell fish, etc.

The phylum Chordata is divisible into the subphyla (1) *Hemichorda*, or worm-like animals with distinct gills, the rudiments of future lungs in the higher vertebrates. None of these interesting animals, are, however, known as fossils. The (2) *Urochorda* or *Tunicata* include the sea squirts and ascidians, and seem to lie on the border line between invertebrates and vertebrates; but these also are not known as fossils. The (3) *Cephalochorda* or *Acrania* include a very small number of living forms, which have been described as "a far-off prophecy of a fish"; none are known as fossils.

The true vertebrates, or the subphylum (4) *Craniata*, include the following classes: *Cyclostomata*, the archaic fishes such as the hags and lampreys; *Pisces* or common fishes; *Amphibia* or newts, salamanders, frogs, and toads; *Reptilia* or turtles, lizards, snakes, crocodiles, and dinosaurs; *Aves* or birds; and *Mammalia* or mammals, the highest animals, which suckle their young with milk.

CHAPTER XVIII

EVOLUTION, THE CONSTANT CHANGE OF LIVING THINGS

Multiplicity of Organic Beings

Number of Living Animals and Plants. — Man is a part of nature, and he has classed himself as the highest Primate, the foremost member of the first among the groups of animals. He lives in an environment of organisms, but of the extraordinary variety of this life he generally has but the slightest conception. It is said that Aristotle (384–322 B.C.) described about 500 different kinds of organisms in his *History of Animals*, and it is probable that he knew more forms than any other naturalist up to a few centuries ago. In 1758 Linnæus noted in his famous work, *Systema Naturæ*, 4236 species, and Pratt in 1911 estimated the described forms as numbering 522,400. Of this total, 284,000, Ashmead states, are insects, and Howard estimates that when all the insects are described the number will be nearer 3,500,000. All of these animals are distributed, according to Stiles, in upward of 120,000 genera, to which each year are added 1150. Of living plants, on the other hand, fully 200,000 kinds are described and it is thought that this total will easily rise to above 300,000.

Number of Fossil Forms. — Among the fossils the number of known forms is much smaller because of the great imperfection of the geologic record. The degree of incompleteness in our knowledge of the organic past can be brought out with striking effect by the statement that upward of 13,000 species of living butterflies have been described, while of fossil forms only 22 are known, and one half of these are from a single locality, Florissant, Colorado. In 1820 there were known 127 species of fossil plants and 2100 of fossil animals. An estimate brought up to date places the number at about 100,000 species, and when this sum is contrasted with that of living described forms, the ratio is as 1 to 5. This, however, is very far from the exact truth, for we are contrasting all of geologic time with the very short present. If, then, we wish to determine the number of kinds of animals that have lived in the geologic past, we must multiply the 522,000 described species of living forms by at least 200 geologic units; as so far deter-

mined for North America, each one of which is at least the equivalent of Recent time; and even then the figures are thought to be far below the actual number of species that have lived. Though it is true that life became progressively more varied with time, still the comparison made is only with the described species and not with the estimated number of kinds that probably are living at present. Therefore it seems safe to state that for every 100,000 kinds of fossil animals that lived we probably know only 1044. "The whole geological record is only the skimmings of the pot of life," says Huxley; it does give, however, a vivid glimpse of the extraordinary array of organisms which peopled the world of the past.

We must now ask ourselves the old, old questions: Have the various organisms always been the same, and whence have they come? Were they *created* as we know them by the special act of a supernatural agency, or were they *evolved*, that is, derived by a process of change, from pre-existing organisms?

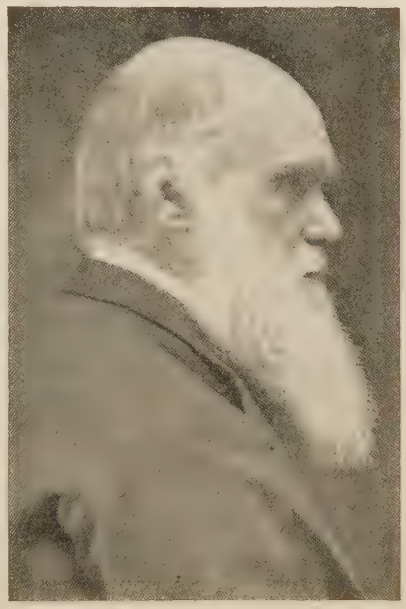


Fig. 313. — Charles Darwin (1809–1882). Father of the theory of evolution.

Theory of Organic Evolution

Rise of the Theory. — The ancient peoples had vague ideas in regard to this profound question, but it was not until the nineteenth century (1859) that Charles Darwin, by the application of true scientific methods, proved in his *Origin of Species* that life is evolved, with change, from previous life. His is the idea of *organic evolution* of species as opposed to supernatural creation.

"Poets, from Empedocles and Lucretius to Goethe and Tennyson, have sought in their verses to illustrate the beauty of evolutionary ideas; and philosophers, from Aristotle and Strabo to Kant and Herbert Spencer, have recognized the principle of evolution as harmonising with, and growing out of, the highest conceptions of science. Yet it was not till the Nineteenth Century that any serious attempts were made to establish the hypothesis of evolution as a definite theory, based on sound reasoning from careful observation."

The ancient tillers of the soil must have been impressed by the great annual miracle of the outburst of vegetable life as spring returns. " From the dead, bare ground they witnessed the upspringing of all the wondrous beauty of the plant-world, and, in their ignorance of the chemistry of vegetable life, they imagined that the herbs, shrubs and trees are all alike built up out of the materials contained in the soil from which they grow. The recognition of the fact that animals feed on plants, or on one another, led to the obvious conclusion that the *ultimate* materials of animal, as well as of vegetable structures, were to be sought for in the soil. And this view was confirmed by the fact that, when life ceases in plants or animals, all alike are reduced to ' dust ' and again become a part of the soil — returning ' earth to earth.' "

Among the eastern Mediterranean peoples arose the ideas that " the world " had a small number of plants and animals that were suddenly created supernaturally, and that from time to time they were destroyed. Thus were the doctrines of *creation* and *catastrophism* developed by these eastern nations, surrounded as they were by sudden floods, earthquakes, and volcanic outbursts (see page 5).

In Egypt, out of a very different environment, grew another doctrine. " Instead of sudden floods and terrible displays of volcanic and earthquake violence, they witnessed the annual gentle rise and overflowings of their grand river, with its beneficent heritage of new soil; and they soon learned to recognize that Egypt itself — so far as the delta was concerned — was ' the gift of the Nile.'

" From the contemplation of these phenomena, the Egyptian sages were gradually led to entertain the idea that all the features of the earth — as they knew it — might have been similarly produced through the slow and constant action of the causes now seen in operation around them. This idea was incorporated in a myth, which was suggested by the slow and gradual transformation of an egg into a perfect, growing organism. The birth of the world was pictured as an act of incubation, and male and female deities were invented to play the part of parents to the infant world. By Pythagoras, who resided for more than twenty years in Egypt, these ideas were introduced to the Greek philosophers, and from that time ' Catastrophism ' found a rival in the new doctrine which has been designated under the names of ' Continuity,' ' Uniformitarianism ' or ' Evolution.' " (Judd.)

Variability of Individuals and Species. — All observant and thinking persons know that a young horse is always a horse and never a zebra or an ass. In other words, animals during their growth do not change into other species, and even though they alter their appearance greatly from birth to maturity, these alterations are characteristic of the form observed and of no other. Therefore it is said that each species " breeds true " in its specific characters, and this relation between parent and offspring is called *heredity*. A close analysis of this resemblance, however, shows that it is never an exact one, for each individual of every species has its own peculiarities. No two organisms are exactly alike and these individual differences are grouped under the term *variation*. In other words, all organisms in their structural and physiological charac-

ters vary more or less in all directions, even though in general they closely resemble their parents.

The Struggle for Existence. — Organic nature in all of her wondrous beauty and astonishing variety appears to the careless observer to be in a condition of ease, play, and contentment. Play, however, generally means getting food, and contentment is at the expense of pain and death to another individual. Truly all organic nature is continually struggling to maintain itself, in the securing of food, in resisting unfavorable environmental conditions, in mating, and in the effort to rear its young. Death is inevitable in the *struggle for existence*, overtaking most of the organisms while they are still young, and hence few are maintained to maturity to propagate their own kind. The world is, nevertheless, and always has been fully populated, since each species unconsciously seeks at the very least to maintain its own numbers or to increase them. For this reason more young are born each year than can possibly exist. Some species produce but a single offspring, while others cast upon the world a million or more during the season of reproduction. Life's struggle is exceedingly harsh toward the young; they are mercilessly weeded out because of unfavorable habitations and starvation, snapped out of existence by a predaceous enemy, or made sick unto death by extremes of heat or cold, or by bacterial diseases. Success in life is the rare exception. In a struggle so severe any advantage, however slight, may therefore be decisive in prolonging the life of the individual and stimulating the origin of new variations. Nature constantly eliminates the unfit, and through the survival of the fittest, a process that Darwin called the law of *natural selection*, the species are maintained, though with constant alteration. The whole course of evolution, therefore,

Fig. 314. — Alfred Russel Wallace (1822–1913). With Darwin, the father of the theory of natural selection.

centers in the processes of reproduction. The favored individuals transmit their valuable qualities to their offspring, generation after generation. "The appearance of the desirable quality is an example of variation; the survival of those individuals which possess these qualities is secured by natural selection; and the perpetuation of the useful qualities is secured by heredity" (Metcalf).

Theory of Use and Disuse. — Jean Baptiste de Lamarck, during the years 1801 to 1815, was the first to elaborate a theory of organic evolution. To him, "Time and favorable conditions are the two principal means which Nature has employed in giving existence to all her productions." Under the diverse influences of the environment "the faculties increase and become stronger by use, become differentiated by the new habits preserved for long ages, . . . and are propagated by generation." In other words, organisms change because of the variability of the environment and through the use and disuse of their organs. This is the theory of *mechanical genesis* so firmly believed in by many American paleontologists.

Fig. 315. — Thomas Henry Huxley (1825–1895). The great defender of evolution and exponent of the natural sciences.

Influence of Environment on Organisms. — So long as the environment of organisms remains unchanged, they undergo comparatively little modification, and such conditions prevailed during long geologic times. However, as the earth's shell has been periodically raised into mountain ranges and the oceans have as often flowed widely over the continents, it follows that the environment of plants and animals has undergone repeated and vast alterations. When the seas flowed over the continents, the habitable areas, or *habitats*, of marine life were enlarged at the expense of the land floras and faunas. The struggle for existence among the land plants and animals was therefore made harder, and evolution was quicker among them. Contrariwise, when the seas contracted, the struggle among the marine forms was enhanced,

due to diminished space, and on the lands the former mild climates were apt to change into more or less arid ones. Not only this, but many times mountains were thrown up simultaneously in many lands, thus bringing on great reductions of temperature and even glacial climates. Such changes led to the "critical periods" in the history of the earth, times especially fraught with danger to the organic world, and affecting deeply not only the life of the land but equally the shallow-water marine forms. Evolution was then especially rapid, blotting out floras and faunas that had long dominated the earth, and forcing the rise of new races which in their turn quickly attained mastery over their physical and organic environment.

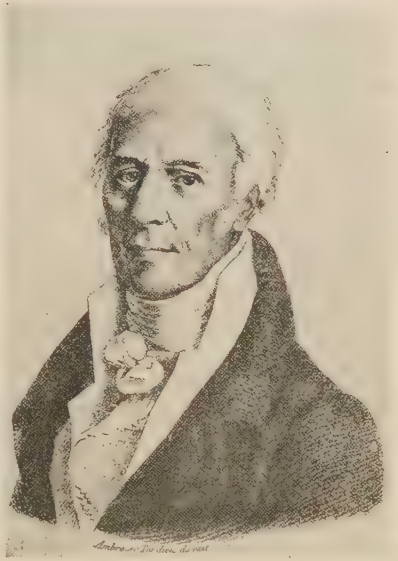


Fig. 316. — Jean Baptiste de Lamarck (1744–1829). Father of the theory of mechanical genesis in evolution.

Striking Examples of Adaptation to Environment. — "Of the several environments to which vertebrates have become adapted, the two which most profoundly modify their inhabitants are the water and the air. This is in part due to the fact that a homogeneous environment pressing upon all sides of the organism with almost the same intensity has moulded the form into a symmetrical contour which offers but little resistance in passing through the medium. . . . .

"Aquatic life modifies its denizens the more profoundly, because it becomes permanently sustaining, while even the best of fliers must ultimately return to the trees, the earth, or the sea. The aërial forms therefore always retain functional structures to enable them to move in the environment whence their ancestors came. Of the more perfectly adapted aquatic types this is not true. . . . .

"Altogether no fewer than seventeen separate evolutions for aërial life have occurred among vertebrates, true flight five and probably seven times, and soaring at least ten times." Four different stocks of fishes have learned to move in the air by flapping their pectoral fins; one frog soars; three stocks of Reptilia either soar, flap, or sail; all of the birds flap or sail; while amongst the mammals seven soar, and one, the bat, flaps its wings. (Lull.)

Among the invertebrates the insects have learned to fly remarkably well and even some spiders can float away in the air attached to long silken strands of their own making.

Of land animals, many stocks have gone more or less permanently to sea. This adaptation is rare among the spiders and insects, common among the reptiles

of the Mesozoic, less common among the birds, and has occurred several times among the mammals (porpoises, whales, and seals). In some of these animals the body transformation has been very great, not only by modification of the limbs, but even by the complete loss of them in some cases.

Finally, the eel-shaped type of body, one of the easiest to propel through the water, has been developed in this medium at least forty-four times, it being a common adaptation among the fishes, amphibians, and reptilians, including the snakes.

Definition of Species. — Lamarck correctly held that species are not fixed entities, and further that there are no sharp divisions in the organic world corresponding to the classes, orders, and genera of our biologic classifications. "A species," he wrote, "is a collection of similar individuals which are perpetuated by generation in the same condition, as long as their environment has not changed sufficiently to bring about variation in their habits, their character, and their form."

Evidence Proving the Theory of Organic Evolution

That all of the manifestations and complexity in the organic world have come about through descent with modification is shown in the following facts: (1) The living organisms are not distributed at random throughout space, but exist where we find them because of prehistoric conditions (Geographic Distribution). (2) All organisms are related to one another and this determined relationship can be readily visualized in a genealogical tree wherein the degree of ancestral parentage is shown in the trunk, main branches, stems, and leaves (Classification). (3) In related adults the organization and structures are alike, and these are unlike in unrelated stocks (Morphology). (4) The lines of descent are in a measure repeated during the earliest stages of growth in the individuals (Embryology). (5) The appearance of plants and animals throughout the geologic past is in harmony with the theory of progressive evolution from the structurally simple to the more complex (Geology and Paleontology). These topics will now be discussed in detail.

Geographic Distribution. — According to Gadow, "The subject of geographical distribution is the dispersal of life in space and time. The key to the present lies in the past." A little insight into the living organisms soon reveals the fact that the kinds of plants and animals are not of universal distribution. Every one knows that elephants and lions are found only in Africa and Asia,

and the giraffe only in Africa, that reindeer and caribou are restricted to northern lands, kangaroos to Australia, and humming birds to North and South America. While this restriction is largely controlled by temperature, yet that is not the whole cause, for we know that the tiger of southern Asia lives also in Siberia, where it has fortified itself against the cold by the growth of a thick fur. Restriction of species is further controlled by mountain ranges, moist and dry climates, forest and open plains regions, and chiefly through isolation of the land masses by the oceans. These are the *barriers* of the biologist, which prevent free intermigration between areas. Another kind of barrier which confronts animals in their wanderings is exposure to the local diseases caused by parasitic organisms. However, these barriers do not explain, for instance, the present wide distribution of the bears in Europe, Asia and America, where they range from the cold north into tropical Brazil, and from Siberia into Alaska, lands that are now separated by at least a hundred miles of ocean surface. But when we are told that in the geologic past Asia and America were united by a land connection, a *land bridge*, and that both had a warmer climate than at present, it is readily seen that the bears could have spread from the former continent into North America and so finally into South America. In other words, the present geographic distribution of organisms is not wholly due to the environment of to-day, but is further conditioned by that of the geologic past (paleogeographic distribution).

Also, similar environments do not produce identical organisms. Life descends from life, and as it is slowly but constantly changing in response to the constant alteration of its environment, the forms change and under favorable conditions the individuals grow ever more numerous and spread in wider and wider waves of wanderings, though, on the other hand, some organisms continually succumb under the struggle for existence. Species originate locally, and though some may remain thus restricted, others spread from their *dispersal centers* into wider areas according to the favoring nature of their surroundings and geography. These conditions are the controlling factors underlying the dispersion of all life, whether of the land or of the waters.

Classification. — The very fact that there are individuals of a kind that can be grouped into species and these into genera establishes the view of relationship. The further fact that in many cases there are no distinct differences separating the species or even the genera is further proof of descent with change.

Morphology (from the Greek word *form*, hence the science of form). — "According to the evolution theory, all higher organisms have descended from the lower by a process of transmutation. . . . This bond of union is first and foremost expressed in the morphological traits of the related species. For as the related animals (or plants) are descended from the same ancestral type, they must possess on the whole the same anatomical structure and organization, more or less modified in each individual case according to the life-habits of the organism. It is this fundamental identity of structure that we mean when we speak of the 'unity of type' in a given class of organisms, while the different parts and organs which are built on the same general plan in the various species are said to be homologous. In contradistinction, analogous organs are such as fulfil the same physiological function without possessing the same anatomical structure, as, *e.g.*, the wing of a butterfly and that of a bird, which, though both serving for flight, are constructed each in a totally different manner." (Herbert.)

Homologous structures offer the most striking evidence for the transformation of species. A good example is seen in the limbs of vertebrates, where the main muscles and bones are alike in a frog, reptile, horse, dog, or man. In detail, however, there are marked variations; in man, for instance, there are five fingers and toes, while the horse has only the third finger and toe remaining, although if we trace the ancestry of the modern horse into the geologic past we learn of fossil horses with three or four functional digits on each limb and with the rudiments of the remaining ones still present to show that the ancestral forms had the primitive five digits in use on each limb.

In the animals just mentioned we pass from homologous structures to *vestigial structures*, for the one-toed living horse still has in each limb the vestiges of the second and fourth digits, known as the splint bones. The same is true in the fossil horses, but in the oldest ones the splint bones are the vestiges of the first and fifth digits. The whales and porpoises of the oceans are descended from land mammals which had four legs adapted for walking, but the front limbs of these ancestors have been greatly modified in the living forms into swimming paddles, while the hind ones are to all outward appearance gone, although in reality the vestiges of them lie buried deeply in the flesh. In most of the snakes not even traces of any of the limbs are present, but in the python or boa there remain bony vestiges of the hind limbs. In the birds, similar loss of the front limbs can be observed, as, for instance, in

the flightless ostrich, whose wings are not fully developed, while in *Hesperornis* of the Cretaceous (Chapter LI) there are no wings, but deep in the flesh lies a single bone, representing the former wing.

Through disuse once useful organs may be largely lost, never to be recovered by subsequent descendants. In many animals the use of remaining relics is not always easily discerned, for these *vestigial structures* are but traces of former important organs. In man there are 180 such vestigial organs which serve no useful purpose, and which prove his animal descent. The human embryo in its earliest growth has a distinct external tail, and in every adult there is the vestigial vermiform appendix, "a small blind process leading from the large intestine, which, serving an appropriate function in vegetable-feeding animals, survived as a useless structure in man, and is at times even a source of danger." (Herbert.)

Embryology. — Embryology is the science which relates to the development of embryos, or the earliest stages of individual growth before the assumption of the distinctive form and structure of the parent. All living things begin their existence in a single cell that may be compared to the unicellular plants and animals, the most primitive condition of organisms; the original or mother-cell in the higher multicellular entities giving rise by repeated divisions to the adult specific organism. In this way each multicellular plant and animal recapitulates in a condensed and foreshortened way its ancestral history. This law was first formulated by the great German biologist, Haeckel, who termed it the *biogenetic law* and defined it thus: "The Ontogeny (development of the individual) is a short recapitulation of the Phylogeny (development of the race)."

In the highest vertebrates, including man, the embryos during their development pass through a series of transformations which represent roughly the evolutionary stages of their lower vertebrate ancestry. In the earliest of these stages there is hardly any difference between the embryo of a fish, salamander, tortoise, chick, hog, calf, rabbit, or man. This can only be explained on the supposition that all of these animals had fish-like ancestors. In the succeeding stages among the mammals, the embryos repeat practically only mammalian characters, thus showing that the ancestral history between the fishes and mammals has been eliminated or crowded out of their embryonic development.

Geology and Paleontology. — A great array of fossils is now known, and their appearance in geological time (chronogenesis) has been determined. Geology begins in darkness, with an ab-

sence of all fossils, but this very want of organic record is evidence that the earliest forms of life were perishable and could not have had the complexity of later organisms. In younger strata, however, there is an abundance of fossils, but nevertheless for a long time there is no evidence of land plants, and a land flora does not appear until still later times.

Not an insect is known until long after the appearance of the land floras. The earliest forms so far found were large plant-eaters and carnivores, but unlike the modern forms. They were followed by the most primitive of modern insects, the may-flies, dragon-flies, and true cockroaches; later appeared still higher types, but the dominant modern forms did not come until the rise of the flowering plants on which they were dependent.

Among animals, the first to appear were all water-breathers, and out of them arose the air-breathers. Not a shred of evidence for the existence of animals with backbones (vertebrates) is at hand until long after the backboneless forms (invertebrates) originated, the first representatives of the higher type being the fishes. Later came the higher amphibia or salamander-like animals, and out of them were developed the primitive reptiles. Reptilian birds with teeth appeared after the reptiles, and these but recently, geologically speaking, gave rise to the modern toothless birds. On the other hand, reptilian mammals originated earlier than the birds, and through a long process of evolution finally gave rise to the placental mammals, the highest type of animals. Finally, the line of mammals leading to man appeared first in the lemurs (monkey-like animals), shortly afterward came the true monkeys, and more recently arose the anthropoid apes and the ape-man.

Such evidence must convince anyone of the fact that the organic world proceeded to develop in an orderly sequence from the simpler to the more complex types of structures and from the lower to the higher mentality. The higher intelligence had its origin, not in the sea but on the land, where the most severe of environments placed a premium on the ability to meet and master new conditions. It was long in the making and not until geologically recent times did mind begin to evolve with wonderful rapidity in most of the mammals, and especially those in the line of man's ancestry. Contrast the intellectuality of the dinosaurs, rulers of the medieval world, with a brain weighing one pound in a body of thirty-eight tons bulk, and man, master of the modern world, with a brain ratio of four pounds to one hundred and fifty of flesh and bone!

The Truth of Organic Evolution. — The question is often asked by those unfamiliar with the work of biologists: Is the theory of organic evolution widely accepted by the students of organisms? The answer is that scarcely any worker in the sciences of Botany, Zoölogy, or Paleontology now rejects the theory; in fact, all work in these studies is based on the concept of life having continuously descended from life with change since it began on the earth. There is now no question about the truth of organic evolution as opposed to the theory of special creation. What is under discussion among the biologists is the method by which nature has brought about the manifold organic changes that we see. No more intricate problem confronts man. It is therefore not remarkable that the entire solution or even the main parts of it are not yet at hand. The secret is buried in each individual and he cannot reveal it, but the time will come when the *modus operandi* of it all will be proved by the biologists. The old notion of eternal unchangeableness with occasional upheavals has given way to the newer idea of progressive development, not only in organic nature but in all matter in space and time. Of Charles Darwin, who first placed this doctrine on a firm scientific foundation, it has recently been said: "In all the glorious company of immortal dead whose earthly frames are gathered in England's great mausoleum, there is no other one who has done so much to modify the mind of thinking man" (Schmucker).

CHAPTER XIX

FOSSILS, THE GEOLOGIST'S TIME MARKERS

Living plants and animals constitute the present organic world, while fossils are the remains of organisms that have lived in the geologic past. Fossils may occur in any sedimentary rock of the low land near the sea, far inland, or even in the highest mountain ranges. They indicate not only the kinds of animals which have lived, but a great deal about the nature of their home surroundings as well. For example: the remains of a marine animal, such as a shark, now found naturally entombed in strata anywhere on the present land indicate that where the relic now occurs the sea existed at the time when the organism was living.

Ancient Views about Fossils. — The fact that fossils resembling in every way the shells of marine animals are now found far inland has long perplexed mankind. Some of the Greeks in the third and fourth centuries before Christ explained them as ineffectual attempts at creation by a *plastic force* inherent in the earth. This poetic interpretation arose again and again in the subsequent centuries, and the " controversy about fossils " was particularly acute after the fifteenth century. These occurrences were then regarded by many as mere mineral concretions and described as *lusus naturæ*, freaks of nature, while others said that these " figured " or " formed " stones were made in the soil of the earth under the influence of the stars. Still others correctly held that fossils could only have belonged to once living plants and animals, but attributed their presence in the rocks to the Deluge, believing that not more than 6000 years had elapsed since the time of the Creation and that the Flood had been universal, destroying all life and spreading its remains far and wide over the lands. " They had no conception of the physical impossibility of accumulating all the fossiliferous formations of the earth's crust within the space of one hundred and fifty days during which ' the waters prevailed upon the earth, and all the high hills that were under the whole heaven were covered,' " as Sir Archibald Geikie has said. Thus arose the " diluvial theory " and with it a bitter controversy that only ceased late in the nineteenth century.

In the Mediterranean countries, however, the younger geological formations " underlie many of the plains and rise high along the flanks of the hills. In these deposits, shells and other remains of sea-creatures have been preserved in such vast numbers as could not fail to arrest attention even in the infancy of mankind. Since the organisms are obviously like those still living in the neighboring sea, the inference could readily be drawn that the sea had once covered the tracts of land where these remains had been left. This conclusion was reached by some of the earliest Greek philosophers [especially Xenophanes, 576–480 B.C.], and there can be little doubt that it led to those wide views of the vicissitudes of Nature which were adopted in later centuries by their successors." (Geikie.) Thus arose the theory of " cataclysms and re-creations," one that was laid aside only in the past century for the theory of evolution, which teaches that life, once originated, has continued uninterrupted to the present.

Transition of Present Life into Fossil Forms. — The easy transition between the living marine molluscs (shell-fish) and their geologic ancestors is best understood by the following examples. The Pleistocene formation is the youngest of geologic deposits and in it, at a given locality, all of the species may be of still living forms, while at another place where the deposits are older, as many as 25 per cent may be of extinct species. In the still older Pliocene, less than half of the forms are of living kinds, and in the next lower formation, the Miocene, only from 20 to 40 per cent are of recent species. Finally, in the oldest of Tertiary formations, the Eocene, there are rarely more than 5 per cent of living shelled animals found.

What Fossils are, and What They Teach

Fossils have two values: (1) as " medals of creation," showing the course evolution has taken; and (2) as indicators of geologic time or chronology. As the first-mentioned value is of most importance in pure Paleontology and general Biology, it need not be treated in detail in this book. The chronogenetic value of fossils is, however, of great import in Historical Geology and needs, therefore, to be studied with some care. All life has constantly changed, not only as to specific form but as a rule in definite directions from the simpler to the more complex types of structures, although often also in the reverse manner. For these reasons, fossils are of the greatest value in determining the past history of the earth.

Evolution and Superposition. — To ascertain the course evolution has taken the fossils must also be studied in the order of their

appearance in any given series of rocks, and this is done by noting their occurrence in the strata. Those in the lower rocks naturally must be older than those in the higher or superposed strata. The order of superposition is usually determined in regions where the earth's crust has not been disturbed, for here bed upon bed of rock occurs as laid down by the waters (see Fig. 205); but where the strata are faulted or deformed into mountains the natural order of stratigraphic sequence is at times very difficult to ascertain. However, after one hundred years of endeavor a great deal of knowledge has been worked out as to the evolutionary sequence of organisms, and this knowledge, as determined in many countries, can now be relied upon to fix in turn the stratigraphic sequence.

Definition of Fossils. — This topic has been briefly mentioned on page 268, but may now be more fully treated. Fossils or petrifactions are the remains or natural impressions or even traces of plants and animals which have lived at some time previous to the present and are now buried in stratified rocks. The degree of perfection may vary all the way from the rare occurrence of an entire elephant preserving not only the skeleton but all the soft parts as well, to the imprint of a leaf in shale or sandstone. Fossils, however, are nearly always only parts of once living things, and it naturally follows that such specimens must have very different values in Historical Geology and Biology. Then these organic traces, though usually of extinct species, may also be of still living forms. In other words, the present life shades gradually into that of the geologic past, this transition being most gentle among the marine invertebrates, while but few of the living species of land-inhabiting vertebrates are known in the geologic formations. This is because evolution has gone on more slowly among the marine invertebrates and the land plants, and most rapidly among the land mammals. Moreover, the accident of burial has much to do with these decided differences between the kinds of organic records, for an animal living in the shallow sea and especially in or on the sea-floor is in the most favorable place for entombment, while only those animals of the land can leave fossils which live in, or whose bodies are swept into, some area where sediment is accumulating; the most abundant land fossils being remains of those animals which dwell on delta plains or partly within the rivers.

Preservation of Organisms. — Fossils always occur in sedimentary or stratified rocks that have been laid down in bodies of water, or on the lands through the action of the winds. Another

type of sedimentary strata having the possibility of fossils consists of volcanic ashes, which at times of outburst are shot high into the atmosphere and then carried by the winds for shorter or longer distances over the lands or seas, burying all living things. In this way the Roman summer resort, Pompeii, was buried by ashes

Fig. 317. — A tangle of fossil moss-animals (Bryozoa). Originally carbonate of lime, now replaced by silica, and etched out of limestone. A true pseudomorph without the microstructure.

from the volcano Vesuvius in the year 79 A.D. To-day in digging out the city some of the victims are found in the form of molds, so that when these hollow spaces in the fine ashes are filled with plaster of paris, good casts of the people and animals as they appeared in the flesh are obtained; such may be seen in the National Museum at Naples. The bones of human victims are also occasionally found under a thin flow of lava, as is the case at Pedregal de San Angel, near Mexico City. However, fossils are not often found under or in the basal sheet of lavas and it may therefore be said that in general they do not occur in igneous rocks. On the other hand, strata that have been replete with fossils may lose every recognizable trace of them by being subjected to the heat of large igneous intrusions, or more commonly by suffering great pressures during times of crustal deformation resulting in ranges of mountains, as described in Chapter XIII. These are the metamorphosed rocks, and whether recognizable fossils are present in them or not depends upon the character of

the sediment of which they are composed and the degree of alteration which they have undergone.

Any dead organism exposed to a temperature above the freezing point of water is, as a rule, at once attacked by bacteria and scavenging animals, and soon vanishes without leaving a trace of its former existence. In this process the oxygen of the atmosphere also assists, and the same is true for organisms under water, only in the latter case complete destruction is slower. The dissolving effects of circulating waters in most cases complete the destruction of even the harder skeletal parts. In other words, the individuals of entire floras and faunas are seen at the present time to vanish

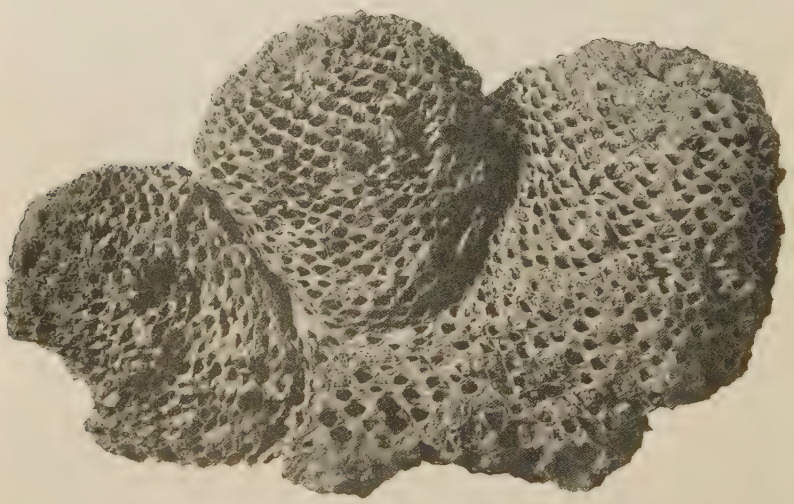


Fig. 318. — A fossil cycad, or plant distantly related to palms. The original wood is replaced by silica, yet the microstructure is preserved. See Fig. 319.

under the influence of other living things, and of the atmosphere and hydrosphere. It is probable that more than 99 per cent of all life has thus been removed. Every organic trace may be oxidized and dissolved into the elements from which it came — into the air, water, and the dust of the earth. Therefore, if an organism is to be preserved as a fossil it must be covered quickly by sediment, and even then only a mold of the exterior form may remain. Complete destruction is the rule among all organisms having soft bodies devoid of hard skeletal parts, and it is the exception among such to leave behind even a mold of their bodily form. Where there is a skeleton, either external, as shells, or internal, as the bones of vertebrates, it again depends upon the

chemical nature of these structures, upon the character of the sediment, and finally upon the chemical content of the waters in the rocks whether these parts are to be preserved or only to give evidence of their existence in the condition of molds.

Nature of Preservable Parts in Organisms. — The skeletons of plants are very rarely made of *silica*, this condition being found only among the single-celled and microscopic diatoms (see Fig. 329). Among the animals, silica is also used sparingly, and is almost wholly restricted to those forms living in the sea. The microscopic diatoms and radiolarians (see Fig. 330) use it freely and among the sponges probably somewhat less than one half have a

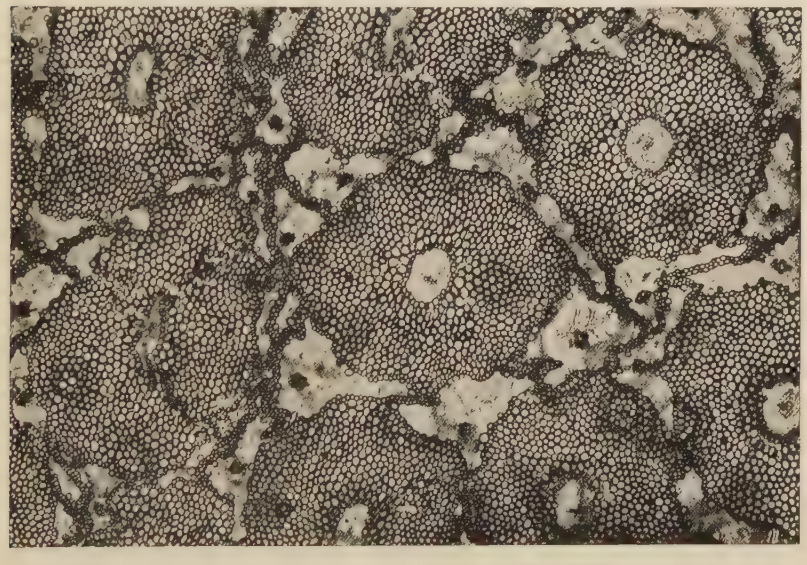


Fig. 319. — The microstructure of a fossil cycad. See Fig. 318.

siliceous skeleton. In these sponges the silica of the skeleton is in the colloidal form (not crystalline but like opal) and is therefore easily destroyed during the process of organic decay; hence the Silicispongiæ (see Fig. 381) are rarely preserved as fossils and are common only in Mesozoic strata. Among the diatoms and radiolarians, however, the silica occurs in the insoluble form and is very rarely destroyed at the time of deposition or afterwards.

Calcium carbonate is used liberally by many types of invertebrates but in plants it is utilized freely only among the marine and fresh-water calcareous sea-weeds. Here the sulphate of lime of the waters is converted by the organisms into the carbonate of

lime of their skeletal structures, bound together by an organic basis. This secretion is known as *conchin* and crystallizes in two mineral forms known as *aragonite* (prismatic in crystal form and cleavage) and *calcite* (cleavage more highly perfect and in three directions equally inclined to each other. See Appendix A). Sometimes a structure consists entirely of aragonite or entirely of calcite, but usually both forms exist in the same individual, as for instance among the Mollusca, where the inner mother-of-pearl layers are of aragonite and the outer porcelanous layers are of calcite. In other cases the calcite predominates, as in the oysters. At times the granules or fibers of mineral matter in the shells are associations of aragonite and calcite. It is very important to know this, because structures in the form of calcite, or in which this mineral dominates, are very apt to be preserved as secreted by the organisms, whereas such parts, when secreted as aragonite, are very rapidly dissolved away during decomposition or are replaced by other minerals through the agency of the percolating waters in the rocks. In the Paleozoic rocks it is almost the rule for the aragonite structures to be gone, this being especially true among the Mollusca, but in the Mesozoic and Cenozoic the mother-of-pearl layers are much more commonly preserved. Just why this is so is not yet determined. The internal skeletons of vertebrates, the bones, are composed largely of phosphate of lime bound together by an organic compound (collagen).

Other much thinner, and usually somewhat flexible skeletal structures consist of a compound of the nitrogenous substances of the ammonia group and a carbohydrate, known as *chitin*. This material has great resistance to chemical agents and is therefore hard to destroy. Among fossils it is often preserved in one form or another. Chitin makes the external skeleton of many kinds of invertebrates, for example, the arthropods (crustaceans, trilobites, insects), and to it is often added lime salts. A similar substance is *spongin*, which composes the fibers in bath sponges; this is rarely preserved among the fossil forms. *Keratin* contains sulphur in addition to nitrogen, and is but very rarely preserved among the fossils; it makes up the hairs, nails and horns of mammals, the feathers of birds, and the scales of fishes.

Preservation of Soft Parts. — It has been stated above that the soft parts of animals are only exceptionally preserved, and it is desirable to mention here a few of the examples of such preservation. Muscles are composed of fibrous material which sometimes is quite tough. If not destroyed by bacterial action, the muscle fibers may be preserved, flattened into thin layers, and in this way

they are often found associated with the skeletons of fishes, even as early as the Devonian, and of reptiles, particularly the Ichthyosaurs (Chapter XLVII) of the European Jurassic. Among the land vertebrates living under dry climates, the muscles and tissues may dry up over the skeleton and be preserved. Notable examples are the Egyptian mummies (none of which, however, are thought to be older than 10,000 years), large parts of the skin of great sloths in the caves of Argentina, and, among the Cretaceous reptiles, at least one large and extraordinary dinosaur mummy (*Trachodon annectens*), which may be seen in the American Museum of Natural History, New York City.

Sir Charles Lyell states that human beings have been buried in the peat bogs of England and Ireland and are preserved intact for hundreds of years due to the antiseptic properties of these marsh waters.

Grave diggers often relate the finding of "petrified human bodies." Such cases relate to fleshy people buried in very wet graves, in which case the entire body or parts of it may be transformed into *adipocere*, a waxy substance of a light brown color. During the slow decomposition of such bodies the organic matter is converted chiefly into an ammonium margarate with an admixture of the margarates of potassium and calcium; it is material that will soon vanish.

The most remarkable preservation of entire animals, however, is the case of those buried in the tundras (frozen ground, mainly ice) of northern Siberia, where great woolly elephants (*Elephas primigenius*) have been kept intact in natural cold storage. How long these carcasses have been entombed in the tundras it is difficult to say, certainly thousands of years, and yet the flesh when exposed on the melting of the ice is greedily devoured by the dogs of the Siberian peoples. The skeleton of one of these mammoths, found at the mouth of the Lena River, and another from Beresovka, with the mounted skin and skeleton and all of the internal organs kept in alcohol, are shown in the Royal Natural History Museum, Petrograd, Russia. A hairy rhinoceros (*Rhinoceros tichorhinus*) has been found in Siberia preserved in the same way, and similar but far less perfect preserval occurs in the frozen grounds of northwestern Alaska. Finally, large parts of the skin of a rhinoceros have been found well preserved in the petroleum seepages of Austria-Hungary.

Molds of the entire exterior of organisms are often found, even of such extraordinarily soft-bodied animals as the jelly-fishes or medusæ, in which the organic substance is at least 95 per cent water. The most wonderful examples of such come from the Jurassic limestones of Solenhofen, Germany.

Color Preservation. — It is exceedingly rare to find among the fossils a trace of their former color. When they are preserved in light-colored shaly limestones, the former color pattern may be present in dark bands, such being known as far back as the Ordovician. The mother-of-pearl color, or nacre, is, however, often preserved and especially well in limy shales impregnated with petroleum, but this color is due to the play of light in the prismatic or aragonitic portions of the shells, and not to a pigment in the material.

How Fossils Occur. — Fossils occur in any one of seven different natural conditions, three of which relate to the substance left by the organisms, three to their form, and one to both. (1) The great majority of fossil specimens preserve more or less of the original hard or mineral substance of the individual plant or

animal, and to this may have been added in the organic interstices more or less of other mineral substance during the process of fossilization, forming the *permineralized fossils*. (2) When the original mineral matter is exchanged for another and usually a dissimilar mineral, with the substitute preserving the original microscopic structure of the organism, the process of substitution is called *histometabasis* (two Greek words that mean *tissue exchange*) (Fig. 319). In this condition the woody parts of plants are often preserved and for study purposes are as good as the similar parts of living plants. (3) Plants may be completely *carbonized*, with the original organic structure more or less completely destroyed during the process. Such fossils have little paleontologic importance, but are of great economic value and are often used as datum planes in Stratigraphy

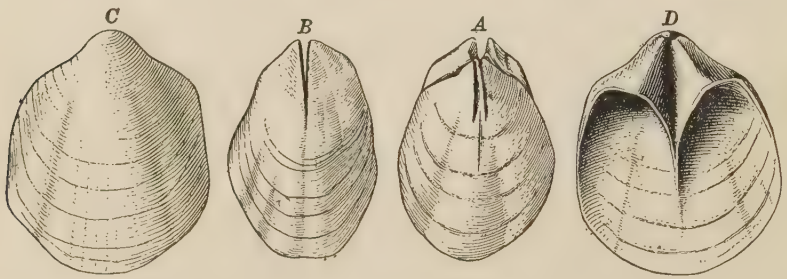


Fig. 320. — Four views of a brachiopod, to illustrate molds and casts. *A*, a natural mold of the interior of the joined shells as seen from the dorsal side. *B*, the same as seen from the ventral side. *C*, an artificial cast of the ventral exterior taken from a mold not illustrated. *D*, an artificial cast of the ventral interior taken from *B*.

and Structural Geology. The form of organisms with the original substance absent may occur in the rocks as (4) *molds*, (5) *imprints*, and (6) *natural casts* (Fig. 320). There is no marked difference between molds and imprints other than that the latter term is applied to impressions of thin substances, as leaves, etc. Natural casts are the counterparts of organisms made by nature by filling the molds of fossils with an uncrystallized substitute; (7) when the replacing material is a crystallized mineral, as calcite, pyrite, and more commonly silica in the form of chalcedony, the replacement is called a *pseudomorph* (from two Greek words that mean *false form*) (Fig. 317, also study Fig. 321).

Tracks of animals crawling around on the muddy floors beneath bodies of water, and especially in the sea, are very commonly preserved. Land animals also often leave their tracks in the geologic

record, but these, when of vertebrates, in most cases occur in red clays or sands laid down in deserts or at least in arid regions. Reptile tracks are often seen in the Carboniferous (Mauch Chunk) and are especially abundant in the Triassic.

Geologic Change in Organisms. — In Tertiary deposits it is the rule to find the marine shells almost unchanged by the addition of mineral matter, and in general it may be added that the older the organisms are geologically, the more mineralized they are apt to be. Probably 50 per cent of all fossils still remain in their original calcareous condition or are but slightly permineralized. This mineralization may take place through the waters percolating in the rocks at any time after the entombment of the fossils or during the time of weathering of the formations, but it is more apt to have occurred during the time of burial, when the ground waters of the sea-floor were charged with carbonic and other acids derived from organic decomposition. For these reasons, the fossil skeletons of organisms occur in all conditions from the unchanged to complete pseudomorphs in calcite, dolomite, silica, iron pyrite, or even lead, zinc, etc.

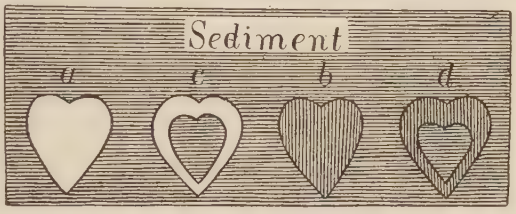


Fig. 321. — Diagram to illustrate molds and casts. The horizontal lines represent sediment, and the vertical ones the subsequent filling. *A*, the natural external mold of a bivalve with the shells removed by solvent waters. *C*, the same shell, but having the original cavity filled with sediment = natural internal mold. *B* and *D*, the molds filled by solvent waters with foreign materials = a cast and a pseudomorph.

Again, the percolating land waters or the ground waters of the sea may have dissolving powers only, and remove all of the organic shells; in this case their former presence is indicated by cavities in the rocks, the molds of organisms, more commonly seen in dolomites and sandstones. These molds are often so wonderfully sharp that the finest artificial casts or squeezes can be made from them. On the other hand, it often occurs that molds, and especially those in dolomites, are covered with a lining of crystallized mineral matter, in which case the fossils are nearly always valueless. Even though molds are bulky to collect, nevertheless they should be gathered, and the casts on the inside of them, the filling of the interior cavities of the organisms, should be secured as well. Imprints

are more commonly seen in the shales and are the impressions in mud of the exterior parts of plants and animals.

Where Fossils Occur. — Fossils are to be especially looked for in the evenly bedded strata of marine origin that are more or less calcareous or magnesian, and least of all in the red shales and sandstones. In nearly all of the red beds other than red limestones it is the exception to find fossil remains, because the plants and animals have been oxidized and dissipated during the process of subaërial sedimentation. It is therefore the green, blue, gray, black, and subsequently oxidized yellow beds that are apt to hold fossils. However, the red shales and sandstones may also have such fossils as the foot imprints or trails of animals, very rarely the bones of vertebrates, and still less often the imprints of plants or chalcedonized woods. In fresh-water deposits fossils are usually very scarce, but subsequent to the Silurian such beds may have plant and vertebrate remains.

Of all stratified rocks, shales make up 80 per cent, sandstones about 15 per cent, and limestones 5 per cent. It is in the limestones that fossils are nearly always present in abundance, but this does not mean that for every foot of limestone, nine of the shales and sandstones are barren of organisms. Carbonate of lime is widely disseminated throughout the strata, and in all the calcareous shales there are apt to be fine fossils that will weather out free; even the calcareous sandstones usually have organisms in some abundance. Further, the thick green and blue shale formations often have thin beds of impure limestone or sandstone and in these bands fossils should be looked for.

Conglomerates may abound in fossils, but here especial care must be exercised in keeping apart the specimens of each pebble, as these may be of very different ages. The fossils of the matrix also must not be mixed with those of the pebbles, for otherwise an impossible chronogenetic association will result. On the other hand, the breccias and intraformational conglomerates have the same species as the binding matrix, because all were formed at the same time.

How Fossils Are Collected. — In looking for fossils there should be no haste, as the work of collecting is always a slow process. It seems to be a common opinion that paleontologists "scent" the presence of fossils, a conclusion that is wholly erroneous, for they are often discovered only after patient hunting.

On any exposure of stratified rocks fossils may occur, and therefore the surface should be scanned for loose specimens. These free fossils are the most desirable because they require the least labor in cleaning, and, further, they show all parts

of the individual. All residual red clays should be searched, as these are often replete with fine free specimens, usually preserved in silica as pseudomorphs.

When loose fossils are found, trace these to the bed from which they come and while doing so note the occurrence of others still in place. Naturally the best places to find fossils are in the hard protruding ledges of limestone, and all such should be broken here and there with the hammer. Sometimes a thin zone will be one mass of fossils, and when weathering has loosened them so that they will fall out freely when hit by the hammer, the easiest way to collect such is to take away a lump from 6 inches to a foot across. In this connection it should be added that weathered rock yields fossils far more easily than that not so affected.

Fossils of a siliceous nature and partially weathered out of limestone should be gathered in bulk, to be treated in the laboratory with dilute muriatic acid (Fig. 317). Material which will bear this treatment is readily tested in the field with a pocket knife; if the blade does not scratch the fossil, but leaves a black mark, it will be well to make the experiment. Of course where the fossils are in cherts or are more or less surrounded with amorphous silica, nothing can be done to free them.

The field geologist in collecting fossils for study by the paleontologist will do well to remember that the value of the work of the latter depends largely on the number of specimens he can study, and therefore as much material as circumstances permit should be gathered. It is not so much a quantity of specimens, however, as it is of species that a paleontologist desires, because it is known that different forms have very different chronogenetic values. As a rule, the more abundant a species, the less its stratigraphic significance.

CHAPTER XX

THE GEOLOGICAL TIME-TABLE

Rise of Classification. — Geologic classification had its origin in the "formations" of two German geologists, Lehmann (1756) and Füchsel (1762); hence our present knowledge of the succession of formations, now called periods, and of the grouping of these into eras of time, is the result of one and a half centuries of endeavor on the part of the geologists of western Europe and America. Even so, we are far from a completely determined chronology.

The older geologists had, in general, no clear ideas of the geographic extent of geologic formations, but Werner (1775–1817), professor of mining at Freiburg, Germany, had such a conception, and on the basis of some facts and much fancy he taught with wonderful success that the formations were universal for the earth; and to this day Geology has not completely divested itself of this fallacy.

Geology was at first a science of minerals and rocks, and it was not until the significance of fossils as determinants of age was first worked out in England by Smith (1799–1801), and still more clearly by Cuvier and Brongniart in France (1808–1811), that stratigraphy and geologic chronology had their beginning. Cuvier taught that each formation contained its own *specially created* flora and fauna, and that each creation was in turn *destroyed by a general catastrophe* (see also page 5). Geologists were largely swayed by these ideas until the appearance of Darwin's famous book, *The Origin of Species*, — although Lyell (the great Uniformitarian) had long previously combated the theories of the catastrophists — when they gradually came to see that life had been continually present and evolving into other forms. The idea of catastrophism has now given way to the theory of local and general changes in the environment, changes that bring about small and great alterations in the plants and animals and in their local associations. We learn, therefore, that the primary basis for discerning the sequence of geologic events is the fossils entombed in the rocks at the time of the formation of the latter. However, many rocks have no fossils, and in the earlier and longer portion of the earth's history the life

then existent was so rarely preserved that other methods have had to be devised to unravel their sequence and genetic relation to one another. These various principles will be described later in this chapter, beginning with the criteria (standards of judgment) of the fossils and then proceeding with those of oceanic spread, erosion, and diastrophism.

The Geologic Column

Here will be introduced the geologic column or time-table, which gives the sequence of the time terms as they will be used throughout this book. These terms are expressive of ideas — for example, Mesozoic for medieval life — or are geographic names, taken as a rule from the area where the formations were first studied — for example, the Comanchian of Texas, from the home of the Comanche Indians. These latter localities hence have become the typical areas with which all other localities having rocks and fossils of the same age must be compared (correlation). The origin and meaning of all of the terms will be explained in the proper places, and the student is urged to commit to memory at least all of the information and particularly the succession of the terms in the three columns on the left of the tables. This knowledge is the *A*, *B*, *C* of Historical Geology, and without it further progress is almost impossible.

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA

(1) Classification Based on Superposition of Strata, and Erosion Intervals

Correlation by Means of Fossils

Eras	Major Divisions	Periods	Epochs		Advances in Life	Dominant Life
PSYCHOZOIC			Recent (Alluvial or Post-Glacial)	Cascadian Revolution	Rise of world civilization The era of mental life	AGE OF MAN
CENOZOIC (Modern Life)	Quaternary	Glacial	Pleistocene		Periodic glaciation Extinction of great mammals	AGE OF MAMMALS AND MODERN FLORAS
	Tertiary	Late Tertiary (Neogene)	Pliocene		Transformation of man-ape into man	
			Miocene		Culmination of mammals	
		Early Tertiary (Paleogene)	Oligocene		Rise of higher mammals	
			Eocene		Vanishing of archaic mammals	
MESOZOIC (Medieval Life)	Late Mesozoic	Epi-Mesozoic Interval		Laramide Revolution	Rise of archaic mammals	AGE OF REPTILES
		Cretaceous	Lance		Extinction of great reptiles	
			Montanian Coloradian		Extreme specialization of reptiles	
		Comanchian			Rise of flowering plants	
	Early Mesozoic	Jurassic			Rise of birds and flying reptiles	
		Triassic			Rise of dinosaurs	

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA (*Continued*)

Eras	Major Divisions	Periods	New Periods	Advances in Life	Dominant Life
PALEOZOIC (Ancient Life)		Epi-Paleozoic Interval	Appalachian Revolution	Extinction of ancient life	
	Late Paleozoic or Carboniferous	Permian		Rise of land vertebrates Rise of modern insects and ammonites Periodic glaciation	AGE OF AMPHIBIANS AND LYCOPODS
		Pennsylvanian		Rise of primitive reptiles and insects	
		Mississippian	Tennesseian	Rise of ancient sharks	
			Waverlian	Rise of echinoderms	
	Middle Paleozoic	Devonian		Rise of amphibians First known land floras	AGE OF FISHES
		Silurian		Rise of lung-fishes and scorpions	
			Taconic Disturbance		
	Early Paleozoic	Ordovician	Cincinnatian	Rise of land plants and corals	AGE OF HIGHER (SHELLED) INVERTEBRATES
			Champlainian	Rise of armored fishes	
			Canadian Ozarkian	Rise of nautilids	
		Cambrian	Croixian	Rise of shelled animals	
			Acadian	Dominance of trilobites	
			Waucobian	First known marine faunas	

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA (*Continued*)

PRE-CAMBRIAN HISTORY (After Barrell)

Archean of Earlier Authors

(2) CLASSIFICATION BASED ON SEQUENCE OF ROCKS, CRUSTAL MOVEMENTS, AND CYCLES OF EROSION
ORDER OF EVENTS ACCORDING TO COLEMAN

Correlation without the Aid of Fossils

Eras	Major Divisions	Periods: Recorded dominantly by surface deposits (Sedimentary and igneous)	Periods: Recorded dominantly by internal structures (Intrusion and diastrophism)	Physical Characters	Dominant Life (Inferred)
LATE PROTEROZOIC (PRIMITIVE LIFE)	ALGONKIAN	**Great Epi-Proterozoic Interval. Over much of the earth the unconformity extends to Algonian Revolution**			
		Keweenawan		Continental sediments and basic volcanics Metalliferous deposits in older rocks	**AGE OF PRIMITIVE MARINE INVERTEBRATES**
		Animikian		Marine sediments dominant Great Iron Series	
				The Eparchean Interval of Lawson	(Fossils almost unknown. Delimitation of base of this age indefinite)
		Huronian		Aqueous and glacial deposits Oldest known fossils	

GEOLOGIC CHRONOLOGY FOR NORTH AMERICA (*Concluded*)

Eras	Major Divisions	Periods		Physical Characters	Dominant Life
EARLY PROTEROZOIC (Primitive Life)	Archean of Later Authors — Neo-laurentian	**Ep-Algomian Interval. Peneplanation of mountains and continents**			**AGE OF PRIMITIVE MARINE INVERTEBRATES** (*Continued*)
			Algomian Revolution	Bathylithic mountain-building Metamorphism and igneous invasion of Sudburian and older rocks	
		Sudburian		Basic lava flows in upper part Conglomerates and quartzites dominant (Temiscaming, Pontiac, etc.)	
ARCHEOZOIC (Primal Life)	Paleo-laurentian	**Ep-Archeozoic Interval. Profound erosion of mountains and continents**			**AGE OF UNICELLULAR LIFE** Protozoa and Protophyta (Fossils unknown)
			Laurentian Revolution	Bathylithic mountain-building Igneous invasion of Keewatin Crustal disruption	
		Keewatin Coutchiching Grenville		Basic volcanics and iron formations Coutchiching schists and gneisses Grenville calcareous sediments	

The Unrecoverable Beginning of Earth History

COSMIC HISTORY

Basis of Chronology. — The fundamental principle underlying all endeavor to make out the geologic past is evolution, the oscillating but progressive changes wrought in the long ages, changes whose interpretation leads to the history of the earth — the science of Historical Geology.

The earth develops as a whole, but the record is far from being everywhere alike; even if it were so, it would not be wholly accessible for study, because sheet upon sheet of rock hides others below, and the atmospheric agencies have destroyed much through erosion. Likewise, the more complete stratigraphic record buried under the oceans is hopelessly lost. Therefore the completed geologic record will eventually be put together from the evidence of all places which are at present land, mainly, however, from the northern hemisphere, because this is preëminently the land hemisphere. Such history is largely brought about through the periodic adjustments of continental and oceanic areas settling down upon a shrinking nucleus, and in so doing crushing the outer shell into great folds which tend to rise, especially upon the margins of the continents. Broad movements of a vertical nature also take place at times, whereby the continents, being underlain by lighter rock matter, tend to warp up and restore the elevations destroyed by erosion, while the floors of the sea, loaded with sediment, tend to sink, as explained under isostasy (page 250).

Evidence of Fossils

Fossils furnish the first step in the process of stratigraphic correlation. Their testimony is checked by the geographic distribution of the sediments that contain them, and by the relation of the latter to the formations beneath and above them (superposition). These principles are easy to state but very difficult to apply accurately to so great a land mass as North America, and even though approximately a century of work has been devoted to it, the ground is only about half covered by detailed studies.

Changing Environment. — In general, sedimentation is a slow process, and under relatively constant surroundings, it is held that but little if any recognizable change in the species is developed, but as the environment of the organisms is continually changing, even though only to a minor extent, these physical alterations cause the faunas at the very least to alter their combinations and to shift from place to place. They die out in one area, but gain a foothold elsewhere, and although this to-and-fro migration is slow when measured in years, yet in stratigraphy the faunal

assemblages appear as if suddenly introduced. This fact has always excited the interest of the paleontologist, and he has explained the phenomenon according to the view of his generation. Once he thought it due to special creations of new types or recoinages of old, but since the time of Darwin it has been looked upon as due to slow evolutions of which glimpses only are obtained in the fragments of the geologic record; or it may be due to shiftings of faunas, or to geologically sudden migrations into the continental or interior seas from the permanent or outer oceanic reservoirs, the continuous realms of marine organic evolution. The fossil faunas from the oceans spread as fast as the sea transgressed the land, and, for practical purposes in stratigraphy, they may be accepted as having appeared simultaneously in widely separated places.

Different Values of Different Fossils. — The localized species (forms restricted to a locality) are of the greatest value in the stratigraphy of small areas, while the new forms which attain wide dispersal are on the other hand of most significance in correlating the time stages in separated regions, for they are progressives, the time heralders, as distinguished from their variously conservative associates. Therefore in the chronologic correlation of the stratified rocks most dependence is put upon a few species, known as " guide fossils," together with the collateral evidence of associated forms.

Dissimilarity of Successive Faunas. — Locally successive, but distinct, geologic faunas derived from the same oceanic realm usually exhibit a more or less ancestral or direct genetic relationship with one another in their structure. In some cases they are the returning, slightly altered descendants of an older fauna, in other words, " recurrent faunas." Therefore the possibility of a " break " in sedimentation between such superposed faunas is easily overlooked and the time value of the recurrent faunas underestimated. Or, two locally superposed faunas may be totally dissimilar, not only in the species but even in the majority of the genera, and yet the time break between them may be a comparatively short one, the reason for this unlikeness being that the two faunas are transgressions, that is, are migrations from different oceanic realms and have therefore had a development from different ancestors.

Three Faunal Aspects of a Period. — A geologic " period " begins as a time of quiet, following a disturbance and uplift of the land. The time of quiet is marked by the erosion of the land and the spread of shallow seas. Waterways broaden and unite across

a continent, only to be drained and destroyed by the crustal unrest with continental uplift which marks the close of periods. During the middle age of the periods, when the oceanic transgressions are greatest, the faunas throughout a continent are most alike in composition and have the greatest number of species in common; these are the "cosmopolitan faunas." Again, faunas of the same age are most dissimilar in the early times of the periods, when the oceanic realms are most confined to certain regions, and the transgressions of the waters upon the continents are smallest. Restriction also takes place during the closing age of the periods, though at these times there are many more hold-over species from the earlier, widely dispersed faunas; in other words, there is no marked introduction of new organic types during the recession of the continental seas. However, when the oceans again spread over the continents, a long time will have elapsed, many of the old familiar forms will have disappeared under the stress of restricted habitat, and new forms will have been developed, the prophets of a new period and indicative of the next trend in evolution.

Physical Evidence

Evidence of Periodic Oceanic Spreading. — Another primary principle of value in marking the periods of geologic chronology is the recognition of the times when the surface of the earth and the oceanic level are in decided motion. It is now clear that North America has been more or less widely flooded by the oceans at least fifteen times since the Proterozoic era, and the other continents have been similarly flooded many times. The movement of the oceans may be of small and narrow extent, as the result of horizontal compression (local or orogenic); or its horizontal and vertical effects may be felt over areas of great magnitude (epeirogenic). Not only do the lands move up and down, the sum of this motion being in the main upward (positive movements), but it is also now clear that the ocean bottoms are periodically more or less in motion, with the sum of their movements downward (negative movements). For these reasons, the oceanic level in relation to the continents is inconstant, and therefore the marine spreadings over the lands, with their concomitant sedimentation, are not only variable in time, but also in geographic extent. On the other hand, when the lands protrude more than usual above the strand-line, the oceans naturally overlap the continents least widely and make at such times limited marine stratigraphic records, which are restricted to the margins and their embayments and to

the persistent axes of depressions, the geosynclines of the continent. As the oceans and seas are all connected one with another, and are also the receivers of most of the land wash or detritus, it follows that a displacement of the strand-line anywhere, through any cause, must be transmitted to all marine waters. It has been calculated that if the protuberant land masses were transferred to the oceans, the general sea-level would be raised about 650 feet, and therefore the North American continent would be flooded to a depth of at least several hundred feet. Then under the waters there is continuous sedimentation, and they abound in more or less of evolving life that is most advantageously situated for burial and preservation; hence the marine stratigraphic sequence is the least broken of the several kinds of historic records accessible to geologists.

It is now known that the oceans have spread periodically and more or less widely over the North American continent, the areal extent of which is about 8,300,000 square miles. These floods occurred hardly at all during the Cenozoic, 1 per cent to 6 per cent of the continent being then covered; four times widely during the Mesozoic, the submergences reaching from 3 per cent to 33 per cent; and, with the maximum spread, apparently twelve times during the Paleozoic, when 1 per cent to 47 per cent of the continent was flooded. More broadly it may be stated that the floods begin and end with shelf seas marginal to the continents and varying in extent between 1 per cent and 5 per cent of the total areas of the continental platform, the conditions being thus not unlike the present conditions of overlap; while the greatest inundations during the middle of the periods attain from 12 per cent to 47 per cent of the continent.

It is therefore apparent why the major portion of the earth's chronology depends for its determination upon the marine sediments. These formations, except in so far as they are later eroded, record the extent of the transgressions, and, in their physical characters, something of the topographic form of the adjacent lands, with a hint as well of their climates; and through their fossils they establish the chronology from place to place. However, this is by no means all, for the newer geology also teaches, as we have seen, that the strand-line is constantly and geographically irregularly in motion, either very slowly transgressing more or less of this or that land, or receding as the lands emerge. Therefore, in no one country is there a total record, but everywhere the story is more or less incomplete, and our chronology is but a patchwork of all the

local histories pieced together into one still very imperfect geologic time-table.

In the marine formations we are, then, everywhere dealing with oceanic *overlaps* whose records for the time being were more or less complete, but each series of beds is also nearly everywhere separated from the adjacent ones by erosion intervals. The latter are due to the periodically recurring emergent times in the history of the continents, which may be either local or of wide extent, the marine records in the latter case being swept away by atmospheric agencies.

Evidence of Erosion. — Geologic chronology has been so far almost wholly, though necessarily, interpreted on the basis of stratified rock accumulations, that is, the marine and continental strata. There is, however, still another record that has so far been almost refused recognition in our time-tables. This is the time evaluation of topographic form at any given stage of development (the physiography of the present, the paleophysiography of the past). To be sure, it is mainly a condition of removal by erosion of previously made histories, but nevertheless the topographic form of the land still remains and has a time value. We all appreciate to a certain extent the significance of unconformities as records of emergence and erosion between periods of inundation, but can any one tell what time value is to be accorded to the complete removal to sea-level of mountain ranges like the present Alps of southern Europe? Many times have similar mountain chains been washed away and then rejuvenated by upwarp to some extent, only to be worn away again after each reëlevation.

Evidence of Breaks. — The erosion intervals are the "breaks," the "lost intervals," or the disconformities in the succession of strata. In addition to the disconformities, there are unconformities due to movements in the shell of the earth when mountains are made (see page 288 *et seq.*).

The breaks are known to be many, but they are far greater in number, and their time durations, although admittedly very variable, are far longer than is usually believed to be the case. The geologic column will probably never be completed on the basis of the recoverable physical and organic evidence, but it will grow into greater perfection for a long time, and this growth will come through the discovery of formation after formation along the lines of these breaks, and more particularly in the areas nearest the continental margins. The perfection of the column will also bring about a greater harmony in the very variable estimates as

to the age of the earth, as given on the one hand by the geologists and on the other by the physicists.

The major breaks in the geologic record are indicated in the time-table by "intervals," the marked erosion periods representative in the main of wide and high continents and of dominant erosion, not recorded by sediments within reach of observation; therefore, in geologic chronology these are "lost times" of long duration. It was not thought desirable to give a new and independent name to each one of these intervals, but rather to use in modified form an old and familiar one. Therefore the Greek word *epi* (upon or after) is here adopted as a prefix to the era terms, to indicate the subsequent time, that is, the intervals. These intervals will then be known as *Epi-Mesozoic*, *Epi-Paleozoic*, *Epi-Proterozoic*, *Ep-Algomian* and *Ep-Archeozoic*. This method of naming was first proposed by Lawson. The same combination can be used, when it becomes necessary, for the intervals between the periods, as *Epi-Silurian*, etc.

Diastrophism

Means of Determination. — As shifting of the strand-line is the most important criterion in ascertaining diastrophic action (a term to include all movements of the outer parts of the earth), it is well to state here briefly how these alterations are most readily determined. Organically they are recorded: (1) by abrupt changes in the superposed faunas, and (2) by the sudden appearance of newly evolved stocks; physically, (3) by more or less obvious breaks in the sedimentation, due to sea withdrawal, (4) by change in the character of the deposits, especially when this involves abrupt transition from organically formed strata (marl, chalk, limestone, dolomite) to mudstone and sandstone, or a change from continental to marine deposition, and (5) by marine overlaps upon rocks of earlier age, producing typical unconformities.

Correlation of formations in separated regions is made in part also on a physical basis. This is done by finding similarities in disconformities (time breaks in conformably superposed or parallel strata, see page 292 and Fig. 243), and changing petrologic characters. A physical correlation is in general, however, far less reliable, and must ever remain second in importance to correlation by fossils for the discernment of diastrophic action. Of course, the most easily determined crustal movements are those which are compressive in character and lead to mountain-folding. Upon erosion and subsequent sea invasion, these angular or structural unconformities are the most easily found and those about which there can be the least doubt. The broad and gentle flexures known as crustal warpings, on the contrary, as a rule bring about the disconformities.

Periodic Movement of Strand-lines. — The crustal oscillations of the earth are not due to heterogeneous and unrelated movements, but are connected, in that areas of elevation and depression remain positive or negative throughout the eras, or during more or less long stretches of geologic time.

The major crustal deformations are periodic in appearance, and their visible areas of movement are now in this continent, now in another; and it is this periodicity which conditions geographic history and organic evolution. All of these active and decisive movements are of long duration, and their major work is confined to the marginal areas of the continents. Farther inland, new axes or depressed folds may rise or old ones be accentuated, and so divide the continental basins into a series of smaller water-ways. Not only are the margins of the continents elevated, but apparently at the same time the oceanic basins are made either deeper or larger, or both. This simultaneous movement of the oceanic bottoms and the continental margins is proved by the fact that the major crustal deformations occur during the emergent times of the geologic periods, and this is true, not only for the continent undergoing deformation, but also for other land masses which have not moved at all, but whose strand-lines have been lowered in consequence of the oceanic enlargement.

The long-enduring middle portion of the periods is marked by relative crustal stability, as shown by more or less reduction of the continents to sea-level (peneplanation). The sediment from the eroded lands adds that much volume to the sea and causes its level to rise as a result of the partial filling. This effect, accompanying the general leveling of the land surface, produces, in the middle of the periods, maximum sea invasion. On the other hand, the earlier times of each cycle exhibit less crustal constancy and more marked erosion. The lands then warp more or less along predetermined lines, due to internal adjustments following the major movement and the reëstablishment of the balance between the sinking and rising areas (isostatic balance or isostasy), which has been altered by those deformations, by the sea invasion, and by the unloading of emergent land areas into the seas of the continents. During the closing stages of the periods, there is a renewal of crustal unrest, seen in the vanishing of the continental seas, which finally ends in another major crustal movement and in more or less complete withdrawal of the seas from the lands.

Rhythm of Strand Movements. — There is a certain amount of rhythm in these periodic movements and this meter permits us

to group the formations into systems or periods. The more active introductory orogenic movements are of comparatively short duration. In contrast, the quieter but broader deformations within the period, of epeirogenic nature, as shown by the world-wide movements of the strand-lines (eustatic movements), are of long continuance. Each submergence with the following emergence is seemingly the natural basis for the delimiting of a period. Among these periodic movements some are far more intense and of greater geographic extent than others, at times when mountain ranges in more than one continent are simultaneously or successively in motion. These are the diastrophic grand cycles, or, according to Dana and Le Conte, the "critical periods" or "revolutions" in the history of the earth, and they divide, as it were, the book of geologic time into chapters.

Terminology

Formations and Periods. — The local warpings as a rule bring about the development of formations and disconformities. These are grouped together into the periods by the "minor diastrophic movements," when local mountain ranges are developed. As there are many of these movements and as they are not of the first order of magnitude, it is proposed to call them *disturbances*, to distinguish them from the rarer but far greater events, the "major diastrophic movements," or *revolutions*, which group the periods together into eras.

It seems probable that the periods were all separated by disturbances, events occurring now in this and now in that continent, but in each case enlarging some oceanic basin and so reacting on the strand-line the world over. On the other hand, during the revolutions, all of the oceans were enlarged by the sinking or broadening of their basins, and all the continents were more or less reëlevated. These latter times are the critical periods in the history of the earth.

Critical Periods and Eras. — The critical periods are marked by the following features:

(1) By wide-spread deformation of the earth's crust, transmitted from place to place. This leads to the elevation of many and widely separated mountain ranges, followed by long intervals of erosion and mountain removal, and therefore by almost universal unconformities. Because of the long-enduring intervals of lost record, the subsequent faunas are not only very different, but appear as if suddenly or at least quickly evolved. Each revolution or critical period is named after one of the prominent mountain ranges formed at the time designated, for example, Laramide and Appalachian revolutions. The subsequent interval is the transition period from one era to the next.

(2) By wide-spread changes in the physical geography. That is, there are at these times a highly diversified or young topography, decided alterations in the continental outlines, the making of new or the breaking down of old land connections (the land bridges which permit intercontinental organic migrations), and marked changes in the oceanic currents, all of which also lead to marked variations of temperature and often to actual glacial periods.

(3) By marked and wide-spread destruction of the previously dominant, prosperous, and highly specialized organic types. This is produced partly by the physical changes and partly by the extensive migrations that are more conspicuous at these times and that therefore invite the spread of death-dealing parasitic diseases.

(4) By the marked evolution of new dominant organic types out of the small-sized and less specialized stocks, and by the development of hordes of new species.

The last or Cascadian Revolution is so recent that the record of it is not lost, and a study of this enables us better to comprehend the changes wrought by the earlier revolutions. Le Conte regards it " as the type, as the best proof of the fact of critical periods, and as throwing abundant light on the true character of such periods, and especially on the causes of the enormous changes in organic forms during such times."

Period Names. — The periods usually take their names from the geographic area where the system of rocks was first considered to be of period value. Thus the Cambrian, Ordovician, Silurian, and Devonian systems were first discriminated in England and Wales, and take their names from ancient peoples living in these countries, or from the district in which the rocks are best developed. Mississippian directs attention to the Mississippi valley, where these rocks are best represented. Triassic has reference to the tripartite development of rocks of that age in Germany, and is an heirloom from the days of Geology when the science had not worked out the principle that formations and periods must be based upon type areas. Cretaceous is a still older inheritance from the days of mineral Geology, the name being based upon the chalk deposits of western Europe.

The Final Geologic Time-table

The time is not yet at hand for a complete evaluation of the minor diastrophic movements, because the recorded geologic succession in the different countries is by no means the same. For instance, the chronology of Africa south of the Sahara Desert is in the main one of erosion, with a wonderful record of continental deposits and glacial formations. In other words, this continent throughout time has generally stood well above the pulsating oceans, and owing to reëlevation in recent geologic periods now stands at an average elevation of 2000 feet above sea-level. North America, on the other hand, lay near sea-level throughout the

Paleozoic, was often in part submerged, and therefore has recorded in its rocks the most complete history of this era; but during the Mesozoic the greater part of the eastern half of the continent was continually above the sea. The Mesozoic marine sedimentary record is, in consequence, restricted to a narrow strip along the Atlantic, to a wider area along the Gulf and Pacific margins, and to the Great Plains country, over which there flowed great inland seas from Mexico to the Arctic in Cretaceous time. To find the Mesozoic history in greater perfection we must look to the countries to the north of the Mediterranean. On the other hand, the Ordovician period is closed in America by the Taconic Disturbance (named from the Taconic Mountains of eastern New York), when low mountains were thrown up from Virginia to Newfoundland, whereas this movement is hardly registered in Europe outside of Great Britain (see also page 636).

Because of these unsatisfactory conditions in our present knowledge of the earth's history, it cannot be stated that the periods in the accompanying table are the only ones that will eventually be recognized in North America. On the contrary, we confidently expect to see evidence developed to show that the Mississippian period embraces two diastrophic cycles or periods (Tennesseian and Waverlian); the Ordovician has apparently four (Cincinnatian, Champlainian, Canadian, and Ozarkian); while the Cambrian also has three (Croixian, Acadian, and Waucobian). To keep these movements or probable diastrophic cycles of period value before geologists, their names have been placed in the fourth column of the table.

In conclusion, it may truthfully be said that there is now a good deal of harmony among geologists in their use of the theory that the surface of the earth is periodically and rhythmically in motion, and that this diastrophic action is the basis of chronogenesis, developing not only cycles of sea invasion and land emergence, and cycles of erosion, but also cycles of organic evolution. Although the eras are clearly recognizable everywhere, nevertheless, until the geologic geography of Europe is worked out in detail, we shall not be able to say that the various *periods* in current use are all established in nature, and it will therefore doubtless be advisable for America to continue to work out her own geologic chronology.

A geological map of North America will be found at the end of this book.

CHAPTER XXI

THE LANDS AND THEIR LIFE

The earth is one of the minor planets attendant upon the sun, and because of the small mass of all the planets, it is under the full gravitative control of the central solar body. The earth is dependent on the sun for practically all of its heat and light, and through these, for nearly all of the activities that have given character to its history. However, another not inconsiderable source of energy is found in the interior of the earth itself (see also page 8).

The Spheres of the Earth. — The vast central mass of the earth, the *centrosphere*, consists of unknown material surrounded by a thick earth-shell, the *asthenosphere*, marked by a capacity to yield readily to long-enduring strains of limited magnitude (Barrell). In other words, the latter sphere is the one of earth weakness, the zone of yielding matter between the firm centrosphere and the outer rocky envelope spoken of as the *lithosphere*. The two outer spheres are together known as the *pyrosphere*, because they have more or less of molten rock. Lying upon the lithosphere, and to a very limited extent circulating within it, is the *hydrosphere* or sphere of water; and outside of all is the sphere of gas and vapor known as the *atmosphere*. Within the hydrosphere, above the surface of the lithosphere, and at the base of the atmosphere exists the *biosphere*, consisting of the living organisms, the plants and animals. Collectively the organisms are also spoken of as the bios, and of the parts of this bios as it changes in the course of geologic time much will be said in subsequent chapters.

The Atmosphere: a Thermal Blanket. — Le Conte has well said that the atmosphere is a kind of blanket put about the earth to keep it warm. So far as life is concerned, this is one of the most important functions it has, though its importance is great in other directions also. The reason for this is that the air is transparent to those rapid vibrations of ether received from the sun which we know as light. On reaching the ground, however, a considerable portion of the light is transformed into much slower vibrations, which we perceive as heat. Now if there were no atmosphere, these heat vibrations would pass off into space and be lost; the result would be that the burning heat of the unmodified sunlight

would be turned into almost the intense cold of outer space at night. This is prevented by the atmosphere, which retains the heat and thus moderates and equalizes the temperature on the surface of the earth. Of the various gases which compose the atmosphere (see page 9), the oxygen and nitrogen are transparent to both the quick light vibrations and the slower heat ones; they could not therefore alone modify temperature in any great degree. The carbonic acid gas and especially the water vapor in the air, on the other hand, while transparent to light, are more nearly opaque to heat vibrations, and it is due to them that the heat is retained. The larger proportion there is of them in the air, therefore, the more equable will be the temperature. This explains why deserts, with their dry atmosphere, suffer such changes of temperature between day and night, while the moist atmosphere of oceanic islands gives them such even climates.

It must not be understood that all sunlight is thus turned into heat, as a portion is absorbed in passing into the atmosphere and another part is reflected back as light and not transformed; it is the remaining portion that is thus effective.

Variable Conditions in the Past. — As a thermal blanket the atmosphere has varied much throughout geologic time. In general, it may be said that the temperature of the air and water has been for long stretches of time fairly equable and genial over most of the earth. Periodically, however, the lands have undergone a severe reduction of temperature and were then more or less widely covered with snow and ice. These cold climates have also reacted on the temperature of the oceans, both because there is less heat in the oceanic waters and because into them are poured the cold waters derived from the lands. In this way the genial climates of the lands and oceans have been changed many times to cool and even cold. At least five cold times in the history of the earth are now known, and it is probable that even more will be discovered.

All of the colder climates fall in with the times when the continents are largest and highest. On the other hand, it is very probable that the climates have very often fluctuated between warm and moist and cool and more or less arid. This conclusion is derived from a study based in the main on the nature of the plants and animals living at any given time, and is further strengthened by the nature of the associated geologic deposits and the degree to which the oceans have from time to time covered the lands. These alterations — and there are many of them — will be pointed out in their proper places.

The Lithosphere

Size. — The *lithosphere* has a polar diameter of about 7899 miles, and an equatorial diameter of about 26.8 miles more. The surface area of the earth, according to Chrystal, is 196,940,000 square miles. Of this, 69.6 per cent (137,000,000 square miles) is covered by water, and 30.4 per cent (59,870,000 square miles) is dry land (Murray, 1912). In the northern or land hemisphere the area above sea-level is about 41,112,000 square miles, while in the southern or water hemisphere it is only about 16,142,000 square miles. It is very important to bear in mind this relation of water area to land surface, because any alteration in the lithosphere or hydrosphere not only reacts on the shape of the continents but more especially changes the totality of their surficial area.

Relation of Continents to Oceans. — The surface of the lithosphere departs from a spheroidal form because the *continental platforms* (see page 251) protrude above the general level of the sea, while the bottoms of the oceanic basins lie below it. The continents are, however, more or less submerged about their margins, and the area under water down to the 100-fathom (600 feet) line is truly a part of the continents, because it is only beyond this that the descent is rapid down the continental slopes into the oceanic depressions. For more detail and diagrams see pages 82 and 103. These marginal shallow-water areas are known as the *continental shelves*, and have an areal extent of less than 5 per cent (9,770,000 square miles, according to Murray) of the earth's surface. Therefore, the continental platforms have an area of 35.5 per cent of the lithosphere, while the remainder, 64.5 per cent, is occupied by the depressed oceanic basins.

The relative areas of the lithosphere above and below sea-level are as follows:

	Per cent	
The highest peak is Mt. Everest in the Himalayas, 29,000 feet		
More than 6000 feet above sea-level	2.3	Land area 30.4 per cent
Between sea-level and 6000 feet above	28.1	
Between sea-level and 600 feet below	5.1	Area of continental platform 35.5 per cent
Between sea-level and 6000 feet below	7.0	Water area 69.6 per cent
Between 6000 and 12,000 feet below	14.8	
Between 12,000 and 18,000 feet below	39.6	Actual oceanic basins 64.5 per cent
Between 18,000 and 24,000 feet below	3.1	
The greatest known oceanic depth is near Guam, 31,600 feet		

Oceans and continents are the grander divisions of the earth's surface, the continents being separate areas, while the oceanic basins are connected one with another and widely so in the southern hemisphere (see Fig. 323). The waters surround the large south-polar land *Antarctica*, and continue north in three great prolongations. Of these the *Pacific* is the oldest and the broadest (6000 miles across), then the *Antarctic* (really not separate from the other oceans), and next the *Atlantic* (North Atlantic 2800 miles in width), while the *Indian Ocean* is the youngest and smallest of these sunken areas. The lands are gathered about the small and shallow *Arctic Ocean* and extend south in two great aggregates, the narrow occidental lands (North and South America, averaging about 2200 miles across), and the broad oriental lands (Eurasia, with an average width of 6000 miles) (see Fig. 322). The latter land mass has, however, in Africa and Australia, two southern prolongations, making in all three, corresponding to the three oceans. Thus the continents and oceans interlock, the former narrowing southward, the latter northward.

Names of the Lands. — The lands are divided into six great geographic divisions, as follows: (1) *North America;* (2) *South America* (Fig. 324); (3) *Eurasia*, or combined Europe and Asia; (4) *Africa;* (5) *Oceanica*, comprising West Oceanica or Malasia, Central Oceanica or Australasia (Australia, Tasmania, New Zealand, and the Fiji Islands), and East Oceanica or Polynesia; and (6) *Antarctica* (Fig. 325).

Islands. — The islands adjoining the continents are properly *continental islands*, and are to be regarded as unsubmerged portions of the continental shelves, separated from the mainland. On the other hand, the *oceanic islands* rise from the depths of the ocean basins, and, as a rule, are volcanic accumulations on the ocean floor. For more detail see page 107.

Mean Elevation of the Land. — The mean height of the continents above the sea is given by Sir Archibald Geikie as about 2400 feet, and the mean height of them severally is about as follows: Europe, 1030 feet (area in square miles 3,700,000); Asia, 3300 (16,400,000); North America, 2100 (7,600,000); South America, 2100 (6,800,000); and Africa, 2100 (11,000,000). Dana says that the material of the Pyrenees spread over Europe would raise the surface only 6 feet; and that of the Alps, although of four times larger area, only 22 feet. Finally, only 6 per cent of the lands (or about 3,300,000 square miles) is 3250 feet above sea-level, so trifling is the total surficial area of the mountains.

The extremes of level in the land not covered by water are about 1300 feet *below* the level of the Mediterranean at the Dead Sea or the Sea of Sodom in Palestine, and 29,000 feet *above* on Mount Everest. For more detail see pages 251 and 252.

Continents

Characteristics of Continents. — Dana defines a continent as "a body of land so large as to have the typical basin-like form,

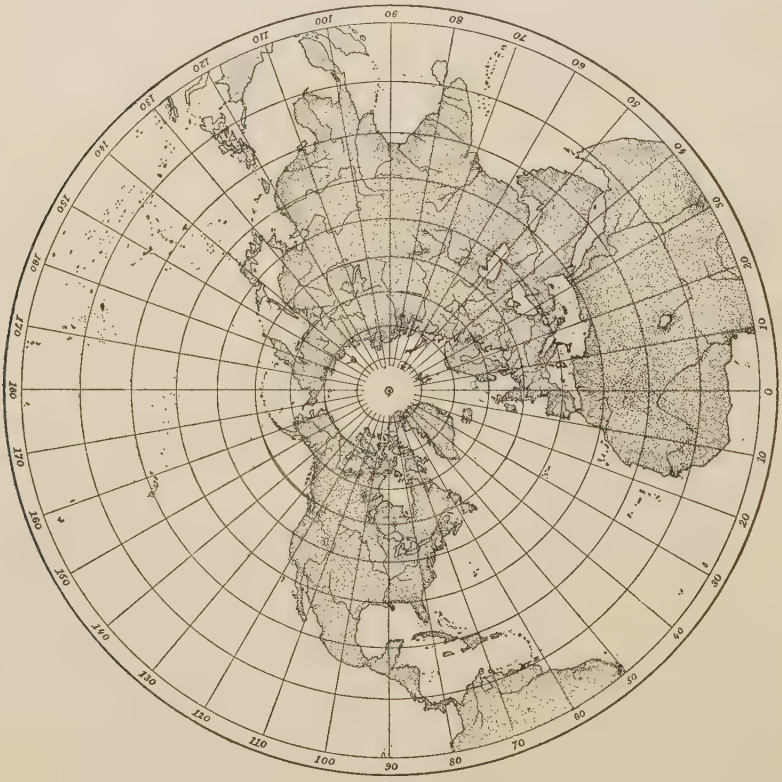


Fig. 322. — Stereographic map of the northern or land hemisphere, showing the lands centering around the Arctic Ocean. After Penfield.

— that is, independent mountain chains on either side of a low interior." As the mountain borders of the continents vary from 500 to 1500 miles in breadth at the base, it follows that a continent cannot be less than a thousand miles (twice 500) in width. The higher border faces the larger ocean; in North America the higher and wider Rocky Mountains face the Pacific Ocean, while

the narrower Appalachians margin the continent on the Atlantic side. Between them lies the continental basin, a vast area drained by the Missouri and Ohio, which flow into the Father of Rivers, the Mississippi. As the Arctic Ocean is small and comparatively shallow, North America in the far northeast is bordered by low and narrow mountains, known as the United States Range. On the south, the small Gulf of Mexico has its compensating elevations in the low Quachitas of Arkansas and Oklahoma.

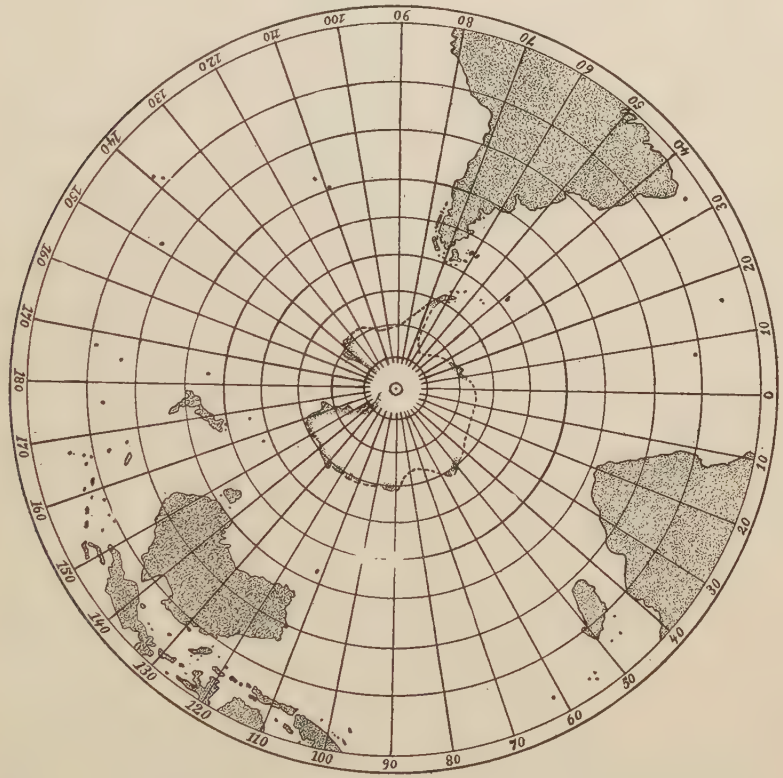


Fig. 323. — Stereographic map of the southern or water hemisphere, showing the south-polar land, Antarctica, and the three continental terminations, South America, Africa, and Oceanica.

The Nuclear Lands or Shields. — Most of the present continents have been formed around ancient protuberances of the lithosphere, the nuclear lands or shields. For the most part these consist of very old igneous rocks and metamorphosed sedimentaries. They are the oldest lands that have remained more or less continuously above sea-level. In general, however, these nuclear con-

tinental masses are not the areas from which the subsequent formations have derived their sediments, for nearly all of them have remained low in relation to sea-level. They appear to have come into existence certainly as early as Proterozoic time and as a rule furnish no fossils. The word *shield* was applied to them by Professor Eduard Suess of Vienna in 1888, because the two best known

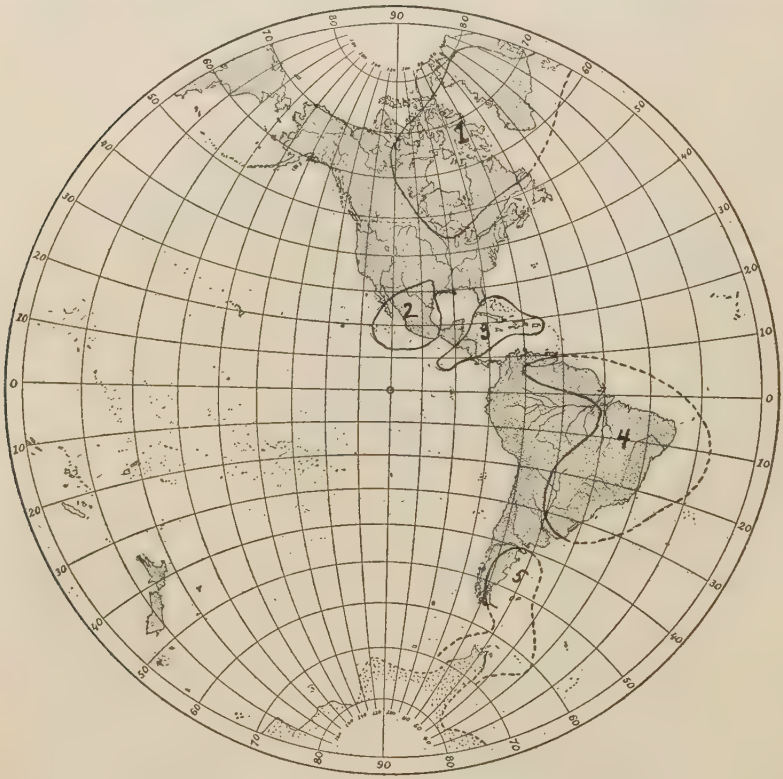


Fig. 324. — Stereographic map of the western hemisphere, showing North and South America, or the occidental lands, and Antarctica. After Penfield. The nuclear lands, or shields, indicated in outline: 1, Canadia; 2, Columbia; 3, Antillia; 4, Amazonia; 5, Archiplata.

examples, the Canadian and Baltic masses, have the form of a depressed shield.

There are at least eleven of these ancient land masses (see Figs. 324, 325). Three occur in North America: Canadia, Columbia, and Antillia; two in South America: Amazonia and Archiplata; two in Eurasia: Baltica and Angara; most of Africa and Australia are shields; peninsular India and Madagascar are remnants

of ancient Lemuria; while the greater part of Antarctica is ancient mountainous land, considerable parts of which rise to an altitude of about 10,000 feet above the sea.

Permanency of Continents and Ocean Basins

Older and Newer Views. — In the earlier days of Geology it was held that there was no stability in the continents and oceans

Fig. 325. — Stereographic map of the eastern hemisphere, showing Eurasia, Africa, and Oceanica, or the oriental lands, and Antarctica. After Penfield. The nuclear lands, or shields, indicated in outline: 1, Baltica; 2, Angara; 3, Ethiopia; 4 and 5, remnants of Lemuria; 6, Australia.

as such, and that there had been complete interchange between them. Even Sir Charles Lyell taught that all parts of the ocean bottoms had been land. Now, however, most geologists hold with Dana that the oceanic basins and the continents have in the main, although not in detail, been permanent features of the

lithosphere at least since the close of Proterozoic time. There is likewise much agreement among geologists in the belief that the oceanic basins are sinking areas, also spoken of as the *negative areas* of the lithosphere, because the sum of their crustal movements is downward; and in general it appears that the oceanic basins have gradually attained not only greater depth but somewhat enlarged area as well. On the other hand, the continents are the rising masses of the lithosphere in relation to sea-level, and for this reason are also called the *positive areas*, because the sum of their movements is upward (see page 228). Of these two great features of the lithosphere, the oceanic basins are the more permanent, while the continents are either locally enlarged or great masses of them are warped under or fractured and depressed beneath the oceanic level. That the internal forces of the earth have wrought great changes in the outlines of the continents and therefore in the shapes of the oceans as well will be shown in subsequent pages. In general, however, it may be said that the present oceans and continents have been more or less permanent features, and that they have been where they now are, with moderate changes in their outlines, since their origin in Proterozoic time or earlier. The greatest changes seemingly have taken place in the equatorial region and in Antarctica south of Australia and South America.

Fig. 326. — James Dwight Dana (1813–1895), at the age of eighty-two.

Proof of Permanency. — The proof that there has been no complete interchange between the continents and oceans is seen in the following facts: (1) On the continents there are almost no deposits of deep-sea origin, and the few isolated cases are met with only on the margins or on continental islands (discussed more fully in the next chapter). (2) The marine deposits on the continents are nearly always those of very shallow seas, in fact, not at all unlike those now accumulating on the continental shelves. Further proof

of this is given by the fact that the contained fossils indicate that the life was all of shallow-water types. If there had been complete interchange, on some continent there should be preserved a long and unbroken oceanic record in both the deep-sea sediments and animals, but nowhere has such a series of materials been discovered. (3) It is now established that the lithosphere is denser and therefore heavier beneath the ocean basins than under the lands, making it impossible for them to have interchanged their positions without destroying the equilibrium of the outer shell.

Deep troughs or geosynclines have, it is true, been repeatedly developed within the continents, near their margins, but even though some of these have in places subsided as much as 40,000 feet, yet at no time have they held other than very shallow seas. This is proved by the character of their sediments and the entombed fossils. Stated in another way, there has been subsidence with compensating sedimentary accumulation. This is certainly true for the Appalachian and Cordilleran geosynclines, out of which there eventually arose the Appalachian and Rocky Mountain systems. This matter will again be discussed in Chapter XXX.

Examples of Continental Fragmenting. — As the ocean basins are the more permanent features of the earth's surface and as they are the periodically sinking areas, it is to be expected that more or less large parts of the ancient continents should have been dragged beneath the waters. As an example may be cited Madagascar, a great island, 975 miles long, with an estimated area of 230,000 square miles, lying in the Indian Ocean off the east coast of Africa. No naturalist doubts its former connection with Africa, because of their similar animals, and yet the channel of Mozambique which now separates it from the mainland is from 240 to 600 miles wide, and represents a land area that has gone down to a depth ranging between 5000 and 10,000 feet. To the northeast of Madagascar lie many small islands, the Seychelles, and to the northwest occurs the Comoro group, all of which are also held to have been parts of Africa and Madagascar. Not only this, but many biologists and geologists hold that all of these lands are but parts of the comparatively recent land Lemuria.

Africa is unlike most of the continents in that it has no marginal mountain chains in the northern and central thirds, other than the Atlas Mountains along the northwestern border. The great peninsula south of the Sahara Desert consists of high plateaus ranging between 3000 and 6000 feet, and the ancient seas invaded

Africa widely only in the north and very sparingly along the east coast. The continent is a great elevated segment or block of the lithosphere with the geologic appearance of broken-down eastern and western margins. The faulted nature of its coasts is further seen in the fact that they are singularly free of large indentations and harbors. South America, on the contrary, has all along its western coast, in the high Andes, the elevated border required for a continent, but along its east coast we seek in vain for folded mountains, and it is therefore held by some of the ablest geologists that eastern Brazil has gone down into the Atlantic.

Gondwana Land. — The broken-down and submerged parts of the continents referred to above are parts of a former great transverse equatorial land, and as there will be occasion to refer to this from time to time, it is desirable to introduce the subject here, though its proper place for presentation is toward the end of the book.

Besides the facts given above, there is much other evidence of a geologic, paleontologic and zoölogic character relating to the distribution of plants and animals since the Paleozoic, tending to show that Brazil was once widely connected with northwestern Africa across what is now the deep Atlantic Ocean. This lost continent is the *Gondwana Land* (from a district of the same name in India) of Neumayr (1883) and Suess (1885) and of the zoögeographers, a vast transverse land stretching from the northern half of South America across the Atlantic to Africa and thence across the Indian Ocean to peninsular India, including Lemuria. It was in existence throughout the Paleozoic, but the Atlantic bridge and Lemuria sunk into the oceans during the Mesozoic. Gondwana when complete was comparable to another transverse land of the north, *Eria* or Holarctica, which existed when North America was continuous with Greenland and Eurasia across Iceland to the British Isles (see Figs. 436 and 488).

Kinds of Rocks Found on the Lands

The materials of the substructure of the continents and continental islands beneath the loose rocks and soil of the surface of the earth (called the *regolith*) consist of three categories of rocks: (1) the igneous, (2) the sedimentary, and (3) the metamorphosed. These various kinds of rocks composing the lithosphere have been described in detail in the first part of this book, and all that is necessary here is to recall in general terms what has been said.

Igneous Rocks. — The igneous or crystalline rocks have risen to the surface from deep within the lithosphere and have intruded themselves (intrusives) into other rocks of the same nature or into the sedimentary strata, or have flowed or been blown out over the surface as lavas and volcanic ashes (extrusives). The originally deep-seated intrusions are, however, now in many places at the surface of the earth, a condition that is due to the fact that the covering rocks, which may have been many miles in depth, have been worn away through the weathering effects of the atmosphere and biosphere. The igneous rocks are most often seen in the mountain regions of the continents and continental islands, in the oceanic volcanic islands, and especially over the shields. They are rarely met with in a flat-lying medial or basin area such as that of the United States. In a general way it may be said that the longer a land has remained above the influence of the invading seas the more likely is the prevalence of the igneous rocks. This is because of the great amount of erosion that has occurred in such places, exposing the deeper parts of the earth's crust.

Metamorphic Rocks. — The metamorphic rocks are altered igneous materials and sedimentary strata. They have been changed from their original characters, due either to great pressures which they have subsequently undergone in the areas of mountain-making, or to the proximity of igneous intrusions. Therefore the metamorphic rocks are seldom met with in areas where the lithosphere has not been deformed, but are usually seen to accompany the igneous materials. The degree of alteration is variable, and may be so complete that the metamorphic rocks simulate even in details the structures of the igneous materials.

Sedimentary Rocks. — The sedimentary strata are bedded rocks that have been laid down in sheets through the action of water and wind. The greatest quantity of stratified formations has been deposited by the seas and oceans. These are the *marine sedimentaries*, and because of the continuous wave and current action of the marine waters the materials are usually well assorted into distinctly layered and clean sandstones, mudstones (laminated shales), and more or less extensive thin- or thick-bedded organic deposits of limestones, dolomites and chalks. The nature of the marine strata will be described in the next two chapters, but in this place further consideration must be given to the deposits laid down by the fresh waters and the wind.

Continental Deposits. — The continental deposits, so named because they are always deposited on the lands by the fresh waters or the wind, instead of by seas and oceans, are formed by moving waters such as rivers (*fluviatile material*), by the more or less stagnant areas of the rivers and lakes (*lacustrine strata*), at the mouths of rivers flowing into the seas and oceans (*delta deposits*), and by the wind (*eolian deposits*). The eolian accumulations are the dune deposits of sand seen along the margins of lakes and the shores of seas, or more extensively in the arid deserts; the wind-blown dust of the deserts or of river valleys in semiarid regions is transported into moist areas, where it may accumulate as *loess*; and finally, much fragmented rocks blown from explosive volcanoes may be carried more or less widely by air currents and left as beds of volcanic ashes. The eolian deposits may be of direct accumulation from the air on the land, in lakes, and in marine waters, but more commonly are reworked and redeposited by the rains and rivers. In continental deposits alone occur also the peat and coal accumulations.

The materials of the continental deposits are rarely as well assorted and as evenly bedded over wide areas as are the marine deposits. The water-borne sands are apt to be dirty and lenticular in occurrence when of river origin, less so

in the deposits of lakes, and least of all in the deltas where the waters of the rivers are backed into shallow bays, and the material is assorted under the influence of the wind and waves. In the delta deposits there is a complete transition from the outer areas of well assorted and evenly bedded marine deposits to the inner regions of poorly assorted and heterogeneous sands and muds of the river flood plains.

Fossils of Continental Deposits. — The continental deposits are more accurately discerned by their contained fossils than by their physical characters; in them one does not find marine animals, although the organisms of the land may be carried by the streams into typical marine strata. It is usually only in the delta deposits that the plants and animals of the land and sea may be so mingled, for here the rivers carry the land organisms into the brackish water areas of the seas and even far into the pure marine waters, this being especially true for the harder woody parts of land plants. However, this transportation, if prolonged, tends to break up and destroy more and more of the land-derived organisms, and therefore the degree of perfection of such fossils in marine strata is always a more or less safe criterion as to the proximity of the land.

The more characteristic fossils of the continental deposits are in general land plants and more especially leaves; land snails and fresh-water snails and bivalves occur frequently, and less often vertebrate land animals such as mammals, reptiles, birds and insects. The animals of the dry land get into the continental deposits most often through the accident of drowning, by falling into or trying to cross bodies of water, more especially at times of great floods or forest or prairie fires. At such times thousands upon thousands have tragic endings, and many are buried in the muds and sands which are so much moved about and redeposited during floods. Entire skeletons of vertebrates may then be buried intact, and these, along with those destroyed and covered by downfalls of volcanic ashes, are, when recovered, the prizes of the natural history museums.

Life of the Land

The life of the land is very different from that of the marine waters, as should be expected because of the diverse environments; the land types live within the gaseous atmosphere and breathe it, while those of the sea are habituated to a denser, salty, liquid medium. For these reasons the fossils as a rule easily distinguish the continental deposits from those of marine origin.

Land Floras. — The floras of the dry land are markedly different and far more highly diversified than those of the seas, where

the lowly sea-weeds play an important rôle and represent the highest stage of plant structure attained. On the land alone occur the forest and fruit trees, the manifold variety of flowering plants, the palms and cycads, the grasses and cereals, the ferns, the ground-pines, and the rushes.

Land Faunas. — Dependent upon these plants are the insects in extraordinary variety, and the same is true of mammals, birds, reptiles, and amphibians. When land animals have become habituated permanently to the ocean, like the penguins among birds, the turtles among reptiles, and the whales, porpoises, and seals among mammals, their organic structures have so decidedly changed as to distinguish them easily from their land ancestors.

When we examine the life of the fresh waters, however, we quickly learn that it does not always differ strikingly from that of the sea. Many fishes of the seas annually migrate into the rivers to lay their eggs, and some have been locked up in the lakes. In the warm climates, crocodiles and alligators live along the shores of the seas, as well as in rivers and lakes. As a rule, however, the bivalve shells and snails of the fresh waters are unlike those of the present seas, while the variety of " shell fish " in the marine waters is so great as to contrast markedly with those of rivers and lakes. This is true not only for the present, but equally so far back into geologic times; earlier than the Coal Measures no fresh-water molluscs are known. The plants of the fresh waters are derived from land forms and some have adapted themselves even to brackish waters, as for instance the mangroves. Among the microscopic plants, however, there is much similarity among those found in all waters, though as a rule the special student finds no difficulty in distinguishing between those of the land and the seas.

CHAPTER XXII

OCEANS, THEIR DEPOSITS AND THEIR LIFE

The Five Oceans. — The word *ocean* is of Greek origin, and came to mean the great outward sea, the Atlantic, as distinguished from the inward sea, the Mediterranean. The word now has reference to the connected bodies of marine water that envelop the earth, of which there are five, Pacific, Antarctic, Atlantic, Indian, and Arctic. The great and deep Antarctic Ocean surrounds Antarctica, the south-polar land, connecting broadly and without boundaries with the Pacific, Indian, and Atlantic oceans; while the smallest and shallowest basin lies over the north-polar area, with limited connections into the Atlantic, and almost cut off from the Pacific by the headlands of Siberia and Alaska. The Pacific and Antarctic oceans are the largest and deepest basins and it is probable that the Pacific, the " Father of Oceans," has always been the greatest in size. The Atlantic and Indian oceans, on the other hand, although ancient, have seemingly attained their present form in very recent geologic time. The Arctic Ocean is apparently very ancient in origin, but its depth has always been shallow when compared with that of the other greater basins. (See Figs. 322–325.)

Mediterraneans. — The mediterranean seas are also to be considered as oceanic areas, since they are not only large but also very deep, though never so deep as are the deepest parts of the oceans. These seas are, in fact, parts of the oceans that are more or less widely enclosed by continents. The typical example is the Mediterranean Sea, lying between Eurasia and Africa; it is also known as the Roman mediterranean, the latter part of the name, meaning a sea in the middle of the land (*terra*), coming down to us from the ancient nations which once ruled its borders. The German name for it is Mittelmeer. Another but less typical example is the American mediterranean lying between the three Americas and walled off from the outer ocean by the Greater and Lesser Antillean islands; it includes the Caribbean Sea and the Gulf of Mexico. The Arctic Ocean is sometimes also called a mediterranean and in many ways it is such, being a deep body of marine water more or less widely surrounded by continents (see Fig. 322).

Epicontinental Seas. — The marginal or epicontinental seas (see page 82 and Fig. 69) are those shallower parts of the oceans that lie upon the margins of the continents, as for instance the Gulf of California, and more typically the row of marginal seas off the east coast of Asia, such as the China, Japan, and Okhotsk seas. The word "sea" is rightly applied to the small, shallow, salt-water bodies above indicated, but in general practice it has become synonymous with ocean (see Fig. 334).

Epeiric Seas. — Still smaller and shallower bodies of marine waters, connected with the oceans, such as Hudson Bay, Gulf of St. Lawrence, and the North Sea of Europe, have also been called marginal seas, but as they are situated wholly upon the continental platforms, they will be called in this book *epeiric seas* (see page 103). These, along with the marginal seas, will be treated in the next chapter, as they are but parts of the oceanic waters invading the continents and lie outside the ocean basins.

Nature of the Oceans

Area. — In the preceding chapter it was pointed out that 69.6 per cent of the surface of the earth is covered by water, but as the continents are more or less submerged about their edges, these marginal or epicontinental seas, at least down to 600 feet, are also truly parts of the continental platforms (Figs. 69, 88 and 334). Accordingly, the actual oceanic areas occupy 64.5 per cent of the surface of the earth. Stated in square miles, Murray places the figure "for the area of the whole ocean" at about 139,000,000. For the actual oceanic areas beyond the continental shelves it is about 129,000,000 square miles.

Arranging the areas according to depth, Murray's table is as follows:

Depth in feet	Square English miles	Percentage
0– 600	9,750,065	7.0
600– 3,000	6,964,750	5.0
3,000– 6,000	5,010,185	3.6
6,000–12,000	26,915,000	19.3
12,000–18,000	81,381,000	58.45
18,000–24,000	9,058,000	6.5
24,000–31,614	216,000	0.15
	139,295,000	100.00

Depth and Volume. — From the above we learn that most of the oceanic areas lie below 6000 feet, and that more than 65 per cent are deeper than 12,000 feet. Areas with a greater depth than

18,000 feet are called *deeps*, of which fifty-seven are now known (see page 83). The mean depth of the oceans is placed at 13,000 feet, and the volume of all the oceanic waters is said to be fifteen times greater than the mass of land protruding above sea-level. If all the deeper parts of the oceans were filled by solid material up to the estimated mean depth, it is said that there would result a universal ocean, covering the entire earth to a depth of a little less than 2 miles. These facts are recited here not only to impress the student with the immense volume of water when contrasted with the small mass of land above sea-level, but further to show, since the waters are mobile and cover nearly three-fourths of the earth's unstable surface, why it is that the oceans are enabled so readily to overflow the lands upon relatively small changes in the elevation of the crust. As the oceans are all connected one with another, a movement of the bottom of any one basin affects the oceanic level in all, raising or lowering the strand-line (see page 223) everywhere simultaneously (eustatic movements).

Original Source of Water. — In Chapter XXVI it is shown that according to the Laplacian theory of earth origin the waters of the earth were regarded as primordial and originating with the primal atmosphere. Following this view, the assumption would be that the original oceans were not only as large in volume as they are now, but even larger, for all of the water in the outer shell of the earth must have soaked into it from the oceans. This theory is no longer acceptable, for, according to the planetesimal theory, there has always been some water in the primal atmosphere, but the greater volume has been gradually added to the surface of the earth through the volcanoes and thermal springs; as Suess says, "The body of the earth has given forth its oceans." In other words, most of the oceanic water was originally water occluded or dissolved in the deep earth, and through volcanic action this *juvenile water* (steam) has been liberated and added to the already accumulated or *vadose water*.

Oceanic Level. — In general practice we speak as if there were a mean sea-level. There is, however, no such condition as a perfect spheroidal oceanic level, or a water surface equidistant throughout each circle of latitude from the center of the earth. Nevertheless, according to Murray, recent researches indicate that the differences of level at different points of the sea-surface do not depart more than 300 or 400 feet from a true spheroid of revolution. This subject is discussed further on page 221 under "datum plane."

Composition of Ocean Waters. — That the ocean waters are quite salt when contrasted with the "fresh waters" of the rivers and lakes is well known, and the subject has already been discussed on page 83 of this book. The volume of salt, when concentrated, is computed to be more than 4,800,000 cubic miles, which if spread over the United States would cover it to a depth of 1.6 miles. The salinity, however, is somewhat variable from place to place, even in the oceans proper, is markedly so along the margins of the oceans where the rivers dilute the sea-water, and is most so in shallow areas under dry climates where concentration may go on continually. The salinity, therefore, may vary from the average of 3.5 per cent and range from less than 1 to over 4 per cent. The composition of the salts is given on the page referred to above.

All of the salts and the nitrogen in the sea as well have been brought down by the rivers, as discussed on pages 43 and 151. Through the action of organisms the magnesium, lime, silica, and nitrogen are taken out of the sea-water, while the clays take up the potash, about as fast as supplied; the common salt, however, seems to have increased constantly in quantity. As the mean annual amount of salts delivered by certain streams is known (see page 151), it has been computed that the amount of sodium now in the sea could not have accumulated at the present rate in less than from 80,000,000 to 90,000,000 years.

The great volume of carbon dioxide in the ocean has been absorbed in part from the atmosphere and probably in largest amount from submarine volcanic action during long geologic time. Thus juvenile CO_2 would naturally be retained by the seas. The free oxygen so necessary for life has also been absorbed in part from the atmosphere, while the rest has come from the carbon dioxide through the action of growing plants. Both are less abundantly absorbed and retained in the warmer waters of the tropical seas.

Life Conditions. — The presence of life in the ocean is conditional upon the *law of the minimum*, that is, it is dependent upon the presence of nitrogen compounds, phosphoric acid, and silica, which are the minimal food elements, those least abundant in the sea-water. If any one is absent there can be no life, and the quantity also limits the amount of life that can exist (see page 104). As the assimilating green marine plants (see pages 409 and 482) use the minimal as well as the maximal foodstuffs and convert them into organic substance, their presence and quantity are conditioned upon the minimal elemental materials. It would seem at first that nitrogen is the first determinant, for where the quantity of its compounds is greater there also occur more assimilating plants. It appears, however, that soluble silica is of first importance, for when this element is most abundant in the North Atlantic, that is, in February, the assimilating diatoms

(microscopic algæ, Fig. 329) take their rise and upon their development follows the wonderful annual ascendancy of animal production and faunal migrations. Murray states that most of the dissolved silica yielded by the continent is tending to accumulate on the frontiers of the temperate and polar zones, especially in the Antarctic Ocean.

Ocean Currents and Temperature. — The earth rotates on its axis from west to east with a speed, in the equatorial region, of about 1000 miles per hour, while at the poles it becomes nothing. This movement, combined with the effects of the temperature differences of the zones, sets up the well-known trade winds of the tropics that blow rather strongly and constantly toward the equator and to the west, and so drag along the warm tropical surface waters. These in turn impinge on the eastern sides of the continents and are then variously deflected, in the main according to the shapes of the lands, causing great streams of heated water, or oceanic currents, to flow toward the poles as previously described, page 85 and Fig. 70. In this way the currents assist not only to equalize the temperature and salinity of the sea water, but also to warm the air in the higher latitudes and to spread the life of the oceans. At the same time the polar waters, receiving but little solar heat and cooled by their great fields of ice, flow equatorward, and, since they are heavier than the warm tropical waters, sink beneath them into the depths of the oceanic basins. Therefore, in all of the depths of the ocean below about 4000 feet the temperature is very low and fairly uniform, near the freezing point of the Fahrenheit scale (35° to 32°, and in the deeper abysses 31°). At the surface the temperature varies from about 80° at 5° north latitude (the warmest area) to about 32° at the poles.

Besides the great ocean currents there are many others of varying intensity set up by differences in temperature of the air and water, differences in the pressure of air and water, and varying degrees of salinity, and still others caused by the winds, the waves, and tidal action. At the surface, the Florida current of the Gulf Stream at its narrowest place has a mean annual flow of 3 miles per hour, but during the warmest and coldest months this rises to 120 sea miles per day. East of New York the rate of flow is about 48 miles per day, and it becomes less and less farther northeastward. From this rapid and exceptional streaming, the rate of flow or *ocean drift* ranges down to zero. In depth the surface currents penetrate very variably, and in general the stronger currents are near the lands along the continental slopes, oceanic

islands, and submerged ridges. As a rule, the penetration is less than 1000 feet, but in the Azores strong currents still exist at 2600 feet. In the tide-swept straits between the Canary Islands moving currents are present at 12,000 feet, and off the continental slope of Ireland they occur at 6000 feet. Therefore the ocean currents sweep the higher swells and ridges of the bottom clean of ooze, and level the bottoms into monotonous, undulating, abyssal plains.

Halistases. — In Fig. 70 are illustrated the oceanic currents and the streamless intermediate areas, one of which is known as the Sargasso Sea. Sargasso, a seaweed common to the West Indian waters, is torn from the bottom by storms and distributed by ocean currents. Much of it drifts into the North Atlantic eddy, where it continues to live for a time, and where grows a rich plankton of microscopic plants. Here also occurs an abundance of specialized or widely distributed and hardy animals — a nomadic fauna (55 species) of small molluscs, pteropods, bryozoans, barnacles, fishes, and crabs. Of such streamless regions there are six known, and they form the *halistases*, or standing seas, of Haeckel.

Light Penetration. — Since it is the green plants which assimilate inorganic matter into their living substance, and since animals depend on plants for their subsistence, it becomes necessary to know to what depths the sun's kinetic energy penetrates into the oceans. Verrill relates that he has dredged red algæ two inches tall attached to boulders at a depth of 480 feet off Eastport, Maine. White objects can be seen in the clear tropical waters with the unassisted eye down to 200 feet, and coral reefs to 145 feet. Here the sun's rays enter nearly vertically, but toward the poles the angle is ever more slanting. Therefore, the vertical penetration is much less away from the equator, and at 67° north latitude the bottom can be seen in clear water only down to 80 feet. However, through the aid of photographic plates, it is now established that considerable quantities of light in the tropical regions go down to 3250 feet, though this is true of only the ultraviolet and blue rays. Even at 1625 feet no red and green rays have been noted, but at 325 feet all of the rays of ordinary bright sunshine are present, though red light is the least strong. The importance of this matter is that the conversion of carbonic acid into plant structure does not go on under the kinetic action of the blue and violet rays, but such assimilation is active under the red, orange, and yellow rays. From this we see that assimilating plant life is practically restricted to the upper 500 feet of the oceanic waters. The portion of the ocean penetrated by sunlight is, therefore, spoken of as the *diaphanous region*, or the zone of transparency, and the dark region, where plants do not live, is known as the *aphotic region*, or the zone where sunlight is absent.

Physical Regions of the Oceans

Areas of Shallow Water. — As the strand, the littoral, and the deeper continental shelf are within 600 feet of depth and properly belong to the continents, they will be discussed in the next chapter.

Continental Edge and Slope. — In general, at the depth of 600 feet occurs the *continental edge*, and beyond this there is a comparatively rapid descent into the oceanic basins, as described on page 105.

The reason why there are continental shelves, and why these terminate at a depth of 600 feet in most places, is because it is at this depth that the ocean storm waves cease to act on the bottoms of the seas. The areas of the continental shelves are, therefore, the regions of agitated waters bordering the lands and capable of holding mud in suspension to depths of not over 600 feet (see Fig. 334). The mud-mantled slopes of the ocean basins mark the slow settling of the mud from the waters beyond the reach of wave agitation. Consequently, in all ages the continental shelves must have been constructed at this depth facing the open oceans. The slope is not steep, however, when compared to the hillsides of the lands. In general, it is long and smooth, with a grade ranging from one foot in ten to one foot in thirty, but extending to a depth of one, two, or three miles. This slope is known as the *continental slope*, and occupies from 8 to about 25 per cent of the ocean areas. Only 5 per cent of the ocean occurs between the depths of 600 and 3000 feet, and about 3.6 per cent between 3000 and 6000 feet (see table, page 471). Below this point the descent is less rapid, for 19.3 per cent of the ocean lies between 6000 and 12,000 feet. Beyond this are the submerged plains with their swells, ridges, and peaks, making up about 65 per cent of the oceanic areas. Within the ocean plains also occur the *deeps*, but their combined areas make up less than 7 per cent of the entire ocean basins.

Regions of Oceanic Muds and Oozes. — The continental edge is also the *mud-line*, for everywhere over the ocean bottoms only fine-grained mud is being deposited; on the continental slopes, green and blue muds, coral mud, and volcanic ash of coarser grain (see page 105 and Fig. 327); and elsewhere, green, blue and red muds of the finest grain. The mud of the continental slopes is mostly derived from the continents and is carried seaward by the action of the waves and the currents; while the impalpably fine muds of the oceanic abysses are very largely of organic origin and mainly result from the microscopic floating forms of plants and animals that

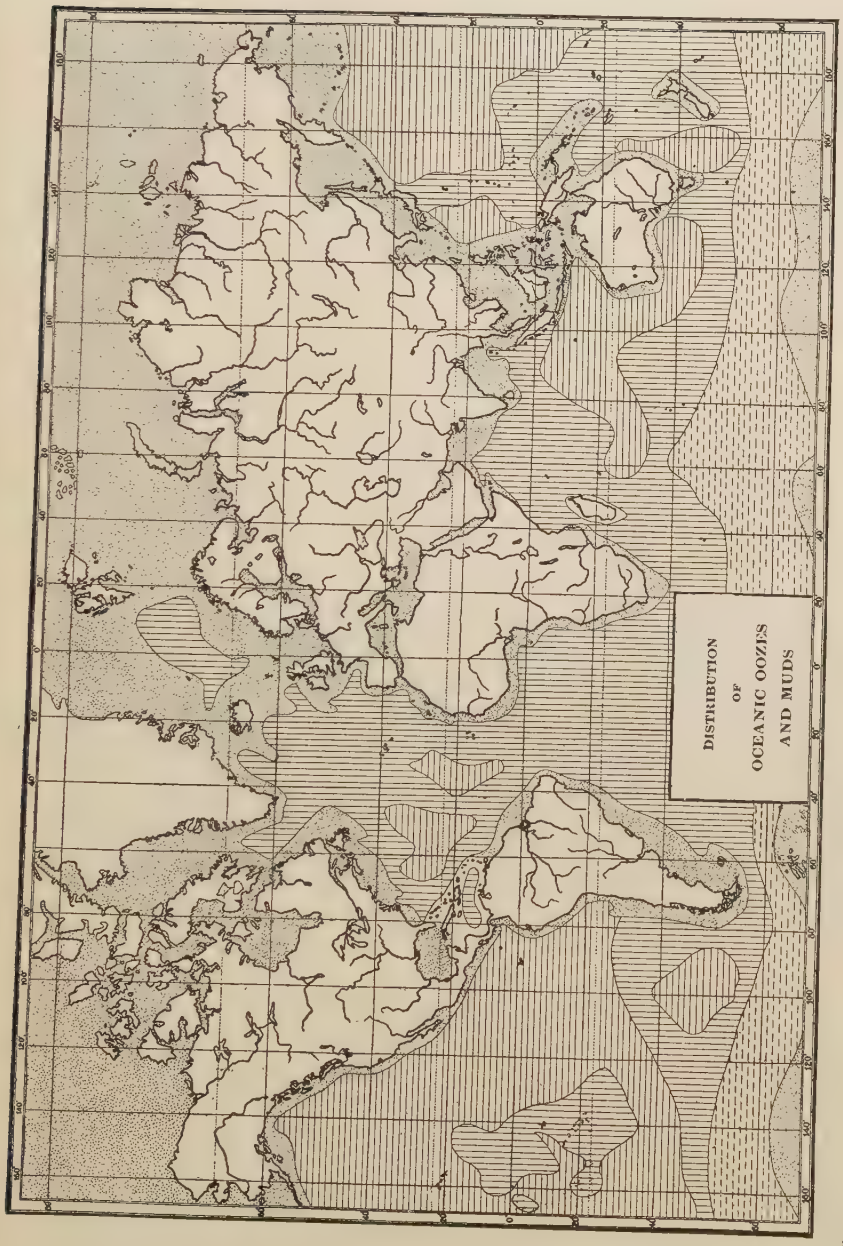


Fig. 327. — Distribution of oceanic oozes, on Mercator's projection. *Dotted*, areas of terrigenous deposits; *vertical ruling*, areas of Globigerina ooze and coral muds; *horizontal ruling*, areas of red muds; *horizontal broken lines*, areas of Diatom ooze. After Murray and Renard, modified from Kayser's *Allgemeine Geologie*.

live in the upper sunlit waters, and upon their death rain into the deeps, where their soft parts are food for the life of the bottom, and their skeletons go to make up the muds of the deep seas. Wind-borne volcanic and desert dust and the disintegrated floating pumice are also contributed, however, and become notable in the composition of the red clays which floor the deepest parts of the ocean basins.

The coarse and very variable deposits of the continental shelves occupy only about 9 per cent of the oceanic areas, 15.5 per cent is covered with the fine blue muds of continental and organic origin (known as the *hemipelagic deposits*), while 75.5 per cent consists of oozes, mainly of organic origin (*pelagic deposits*). As the sediments of the shelf seas and of the continental slopes, occupying together about 25 per cent, are so largely derived from the adjacent lands, they are also spoken of as the *terrigenous deposits* (Fig. 327).

Blue and Green Muds. — In any classification it is difficult to draw sharp lines, and though the great mass of blue muds is laid down beyond the continental edge and mainly on the continental slopes, still they are also found on the continental shelves in the quieter water of less than 600 feet depth. This fine mud

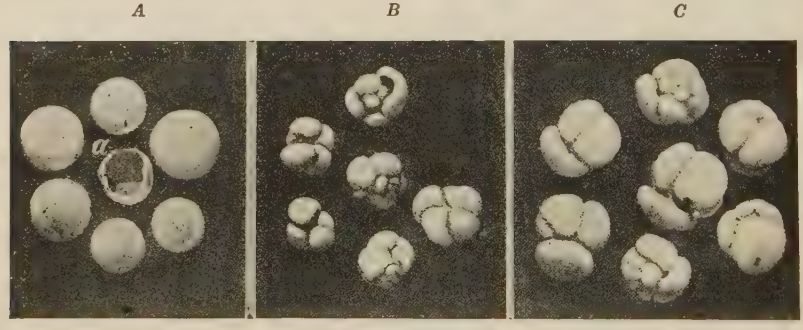


Fig. 328. — Three species of Foraminifera washed out of Globigerina ooze. × 12. *A*, *Orbulina*; *B* and *C*, *Globigerina*. After Flint.

is brought to the seas by the rivers, but only the finest of it is held in suspension long enough to carry it beyond the average depth of wave action at the continental edge. It owes its blue color to the fact that the iron of the mud is united with organic matter, but where the mud has been oxidized and the organic matter removed the mud takes on a red color, such as is seen in the Yellow Sea off Asia and certain areas off the coast of Brazil and western Africa. In the main, however, the hemipelagic muds are blue in color, and they shade seaward into the oceanic oozes. *Green mud* is only a variety of blue mud and derives its color from the presence of grains of glauconite (a silicate of alumina, iron, and potash, with water). These muds are found on the continental slopes near bold coasts and where currents from different sources alternate with the season, as off the Atlantic coast of the United States.

Volcanic muds, the ashes of volcanoes, are found at nearly all depths, because volcanoes are situated not only along the borders of the continents but also in various parts of the oceans. The ashes blown high in the air are transported far and wide. They dominate the nature of the deposits, however, chiefly in the deepest parts of the oceans, because there all the calcareous débris from the animal world is dissolved as fast as it originates, leaving a scanty insoluble residue.

Globigerina Ooze. — Globigerina ooze is a fine organic mud with more than 30 per cent of calcium carbonate, derived in the main from the tests of the microscopic animals known as Foraminifera, of which *Globigerina* and *Orbulina* are the most prevalent forms (Fig. 328). These animals, of which there are about twenty kinds in tropical regions, live in the sunlit waters and after their death drop into the abyss. To them in the warmest waters are added other micro-

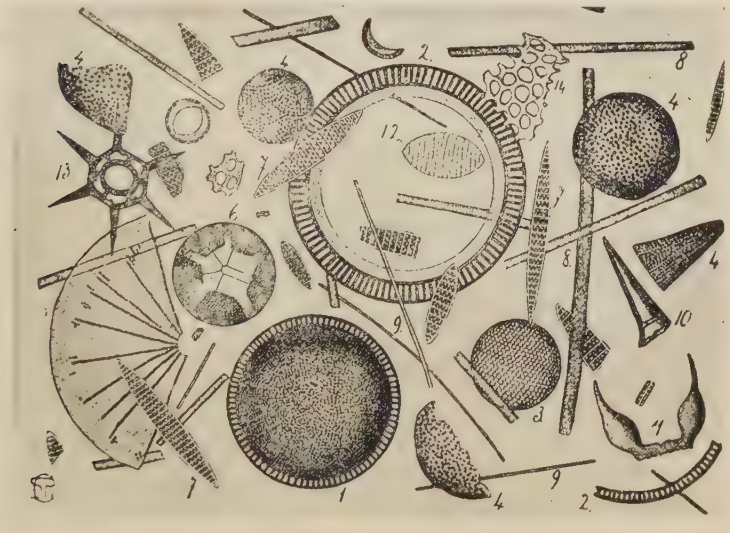


Fig. 329. — Many species of Diatoms washed out of Antarctic Diatom ooze. × 300. From Krümmel's *Oceanographie.*

scopic calcareous particles derived from lime-secreting algæ (coccospheres and rhabdospheres, Fig. 332). This type of ooze is more widely distributed than any other, and usually occurs in depths of less than 15,000 feet and more than 6000 feet, although around tropical oceanic islands it may form in the shallowest of seas. On the one side the Globigerina ooze merges into the blue muds and on the other into the red clay, for at greater depths than 15,000 feet the solvent powers of the abyssal waters, as previously stated, dissolve the lime and carry it away in solution. The Globigerina oozes originate in the warmer waters and occupy nearly 30 per cent of the ocean bottoms (Fig. 327).

Diatom Ooze. — In the surface waters of the oceans also live microscopic plants that secrete beautifully ornamented siliceous tests, and of these a single species is particularly abundant in the polar waters (Fig. 329). Their tests after death

fall into the deeps and there form the Diatom ooze, which occupies about 6.5 per cent of the oceans in high latitudes (Fig. 327). See also page 107.

Radiolarian Ooze. — The Radiolaria are microscopic animals that also secrete very beautifully shaped and ornate tests of silica; while they occur in all oceans they are most abundant and varied in the tropical regions of the Pacific and Indian oceans (Fig. 330). The area of these oozes is small, being about 3.4 per cent of the oceans. Murray states that the Radiolarian ooze may be regarded as a variety of red clay containing many radiolarian skeletons (Fig. 327).

Fig. 330. — Many species of Radiolaria washed out of Radiolarian ooze. × 60. After Krümmel.

Red Clay. — Red clay is usually found in depths greater than 16,000 feet and is the most widely distributed of the oceanic deposits, occupying about 36 per cent of the oceans (Fig. 327). The red color is due to oxide of iron. The clay, Murray tells us, is in the main a hydrated silicate of alumina, derived principally from the decomposition and disintegration of pumice and other volcanic products long exposed to the action of sea water. In the greatest depths there is no calcium carbonate present, but in the lesser depths the clay shades over into the Globigerina ooze, and there may be as much as 30 per cent of it in the clay. On the other hand, the red clay merges into the Radiolarian ooze. The rate of formation of red clay is exceedingly slow. In it have been detected grains of meteoric dust.

Age of the Oceans

Lack of Abyssal Deposits on the Continents. — Geologists have long sought on the continents for geologic sediments comparable to those now forming in the great abysses of the ocean, but to no avail. The German geologist Walther, who has carefully examined recent abyssal sediments, in his geologic studies has considered repeatedly whether any fossil rock possesses abyssal characteristics, and nowhere has he met with strata, either of Paleozoic or Mesozoic age, that by their structure and nature of deposition correspond to the present sediments of the oceans. Sir John Murray also failed to find oceanic rocks. However, a microscopic and chemical analysis of certain deposits on islands such as Barbados and Trinidad of the American mediterranean, Sicily and Malta, and possibly Haiti, Jamaica and Cuba, shows that oceanic deposits of Tertiary age occur on them. Chamberlin says: "The cases in which true abysmal deposits now appear above the sea-level do not, when all are put together, appear to attain in area so much as one per cent of the total earth surface. Moreover, nearly all of these oceanic deposits lie in the zones of exceptional crustal instability." This evidence is, accordingly, in harmony with the theory that the oceanic areas have in the main always been oceans, or, in other words, that the oceans are permanent features of the earth's surface.

Modern Origin of Abyssal Animals. — In the abysses there is not a trace of Paleozoic life, though from twenty-five to thirty-five genera, with a larger number of species, are known in the present shallow seas. Again, an analysis of the present abyssal animals reveals no ancestors older than the Triassic, and most of them date from the Jurassic and Cretaceous. Walther concludes from this evidence that the present deep oceanic fauna migrated from the shallow waters during Mesozoic time, and that "the peopling of the deep sea can be traced at the earliest to the Triassic."

While this evidence is correct, it does not necessarily follow that the oceans have all become abysmal since the close of the Paleozoic. While the juvenile water added to the oceans since that era has been considerable, yet it may not exceed 10 per cent; we see, accordingly, that these basins must have been long previously nearly as capacious as they now are to hold the vadose waters. Moreover, we must not forget that Gondwana was broken through by the Atlantic toward the close of the Mesozoic, and Eria during the Tertiary — areas that have taken up great quantities of water and thus brought about a general reduction (eustatic) of the sea-level. It is this geologically recent fragmenting of the continents that has resulted in the present high average level of the lands above the strand-line.

Life of the Marine Waters

Plankton. — The life feature of prime importance in the ocean is the *plankton,* a term that Haeckel proposed for the passively floating life of the sea, which is also a part of the *pelagic life.* The great majority of the plankton is made up of primitive plants (mainly algæ, Figs. 329, 331 and 332) and animals (mainly Foraminifera and Radiolaria, Figs. 328 and 330, and, at certain seasons, the larvæ of higher animals) that are microscopic in size. It has been variously described as " a wealth of life more abundant than is contained in the richest and most luxuriant forest," " the drifting fauna and flora of the sea," and " the pastures of the sea "

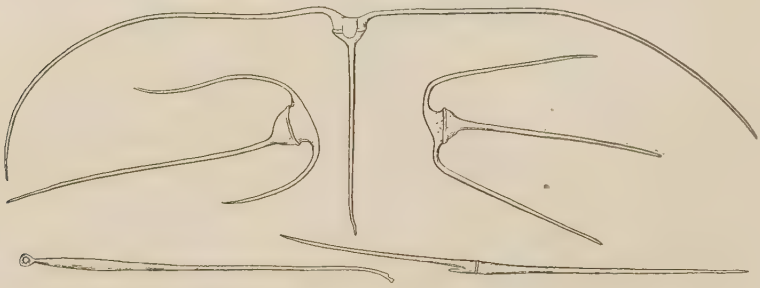


Fig. 331. — Three species of pelagic algæ (Peridinians). Greatly magnified. From Chun's *Tiefen des Weltmeeres.*

as compared with " the grass of the fields." The quantity and variety change from place to place and with the season of the year, being far more abundant close to the lands and in temperate waters than out in the open ocean and in polar seas. Of microscopic unicelled plants alone there are in the densely populated region of the northern Atlantic from 3000 to 12,000 individuals in a quart of water, though ordinarily there are not more than 300. The plankton lives and propagates mainly in the upper 300 feet of the seas, though in greatly diminished quantity it exists down to 1100 feet, where no more is found. It is the cause of most of the phosphorescence seen glowing at night, for much of it then rises to the surface. On hot, sunny days it floats at from 30 to 160 feet beneath the surface.

The plankton is the food for most of the animals living on the bottom of the oceans, which are collectively known as the *benthos,* and all animals that swim freely about are dependent for sustenance upon it. In other words, the plankton is the ultimate source

of food for all marine animals. The planktonic plants, when growing, take in carbonic acid and free the oxygen, bringing about more favorable habitats for animals, a condition attained in greatest measure in temperate waters.

Life of Shelf Seas and Continental Slopes. — The realm of greatest abundance and variety of life is in the shelf or epicontinental seas bordering the continents, and while the largest quan-

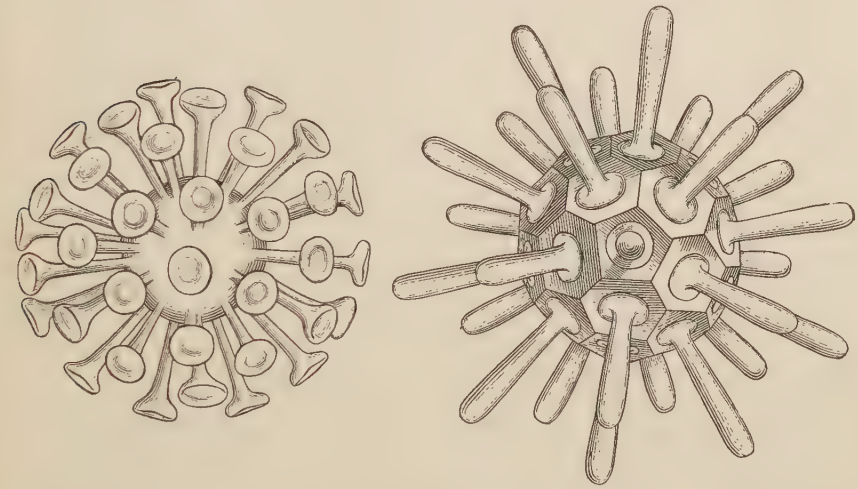


Fig. 332. — Two species of Rhabdospheres, lime-secreting algæ. × 2200. From surface of Atlantic Ocean. Challenger Expedition Reports.

tity is in the temperate waters, the greatest number of kinds occurs in the warmer waters. Bottom-living plants, the seaweeds, are most prolific in waters down to about 400 feet, and none are known beyond 600 feet. This is the most striking difference between the life of the shallower waters and that of the oceans proper, for the animals of the deeper parts of the shelf seas continue down the continental slopes, and, even though in reduced quantity, they are still comparatively varied and abundant at depths of 9000 feet. Beyond this they diminish quickly and over the abyssal plains they are very scarce indeed, consisting only of forms highly modified to cope with the peculiarities of their environment.

Kinds of Abyssal Animals. — Sir John Murray in the famous *Challenger Reports* presents a summary of all the abyssal animals

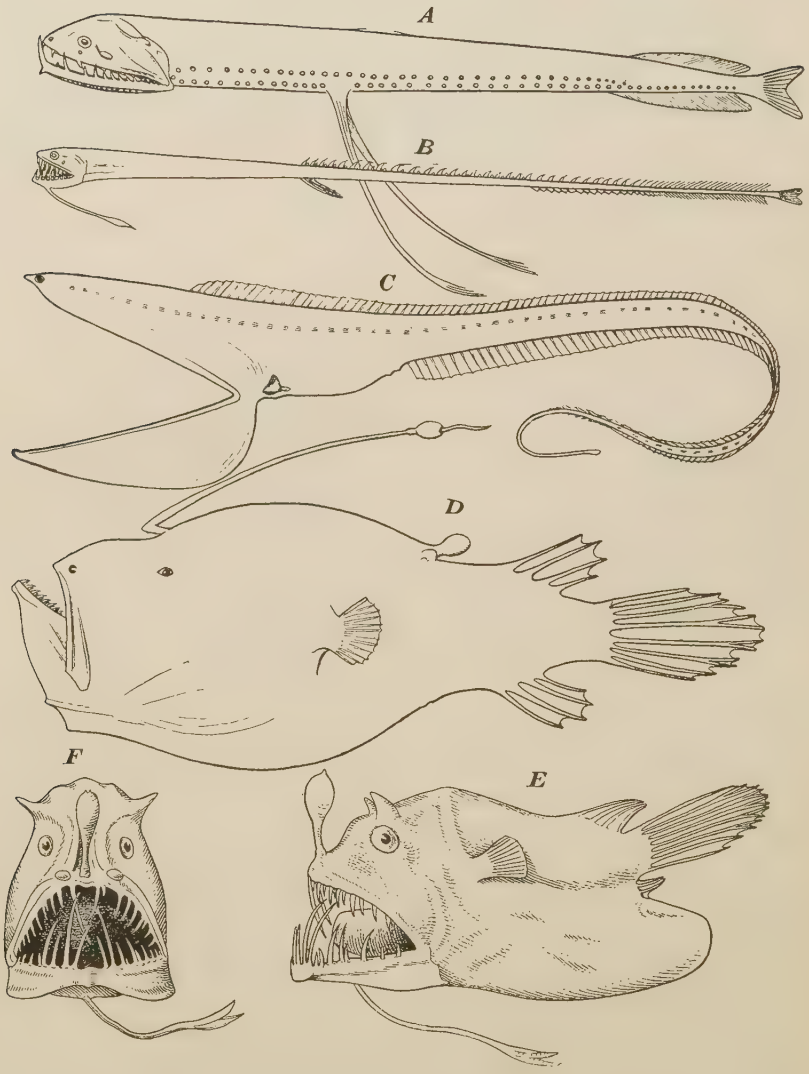


Fig. 333. — Five species of small, black, deep-sea fishes. After Goode and Bean, *Oceanic Ichthyology*. *A*, *Photostomias guernei* (length 1.5 inches, taken at 3500 feet); *B*, *Idiacanthus ferox* (8 inches, 16,500 feet); *C*, *Gastrostomus bairdii* (18 inches, 2300–8800 feet); *D*, *Cryptopsaras couesii* (2.25 inches, 10,000 feet); *E*, *F*, *Linophryne lucifer* (2 inches).

known up to that time (1895), and his figures have not been much modified since. They are as follows:

At	650 feet,	more than	5000	kinds	of	bottom	animals	live	
"	6,500	" about	600	"	"	"	"	"	"
"	13,000	" "	400	"	"	"	"	"	"
"	16,250	" "	150	"	"	"	"	"	"

Previous to 1910, only thirty-five specimens of abyssal or bottom fishes had been taken, representing twenty-one species. This scarcity of specimens is equally true among the bivalves, brachiopods, bryozoans, crinids, starfishes, hydroids, actinians, and corals, the most abundant animals being the sea-cucumbers, ophiurids, and sponges. Finally, on the red clays there is almost no life, other than a few worms, because of the great scarcity of food. In general, it may be said that the abyssal life is small, frail, and devoid of thick and strong skeletons. (Hjört.)

Phosphorescence of Oceanic Life. — The waters at the bottom over the abyssal plains are everywhere dark, icy cold, and almost without movement. In addition, the pressure is great, and as there are no barriers the highly specialized animal life, in the main invertebrates, has migrated quite uniformly over them. The sparse fauna consists mostly of blind forms, and where eyes have been inherited and are still functional, as in some fishes, they are enlarged to great size that they may catch any ray of light, for nearly all abyssal invertebrates are phosphorescent, thus being able to " transform the dark depths into a magic garden."

Intermediate Abyssal Fishes. — There is another realm for abyssal fishes, but this lies far above the bottom of the oceans, between 480 and 4800 feet, with the greatest abundance at about 1000 feet beneath the surface. About 1000 species have been described from this zone, and they are now known to be of more or less localized forms, living at lower levels during the day and at higher ones at night. At the lowest level these fishes are apt to be black or red, colors invisible at this depth because of the absence of red light, and some have telescopic eyes adapted to make use of the blue and violet rays of sunlight. The abyssal fishes are small, black, strange-looking animals, their large heads nearly all mouth and teeth, with long sensory tentacles or feelers and " torches " with phosphorescent tips, and an abundance of glowing spots distributed in lines over their sides. " The higher we ascend towards the surface of the sea," says Hjört, " the more varied become the forms and colors of the organisms, and the more diversified become, also, their conditions of life." (See Fig. 333.)

CHAPTER XXIII

SEAS, THEIR NATURE AND DEPOSITS

In the previous chapters we saw that the oceans are more than full, and that they have spread over the continents to the extent of about 600 feet in depth, developing the shelf or marginal seas and the epeiric seas. It should, however, be added that the continental shelf is known to have depressions in it as deep as 1600 feet, though such is very rarely the case.

Definition of Seas. — In general use the word *sea* is interchangeable with ocean, but in Geology it is more often used in a restricted sense and in its original meaning. It appears to have originated with the peoples of northwestern Europe who were familiar with the North Sea and the East or Baltic Sea. These are bodies of marine water that in the main are under 200 feet in depth, and lie upon or within the continent; hence they contrast distinctly with the far deeper and larger mediterraneans and the abyssal oceans (Fig. 334). The marginal or shelf seas are also known as *epicontinental seas* because they lie upon the borders of the continental platforms (see page 82 and Fig. 69), and the Germans often call them " flat seas " because of their shallowness and their flat bottoms.

The seas of the continental shelves are not only the regions of greatest abundance of marine life, as previously stated, but also the ones from which all the other water bodies of the world have been colonized. Thence, bottom-living forms and swimming organisms have made their way into the abysses and others have voluntarily or involuntarily attained to a life in the inland lakes and rivers through modification of their habitats from salt to fresh waters, or, by changing water-breathing organs into lungs, have even become denizens of the dry land itself.

Epeiric Seas. — In the geologic past all of the continents have been more or less widely flooded by overlaps of the oceans, all of which are thought to have been shallow and usually under 600 feet in depth, though in places they undoubtedly were deeper. Long ago Dana called these *continental interior seas* or *interior seas*, and his terms should have prevailed, but unfortunately the name " continental deposits " came to be applied later, not to the sediments of

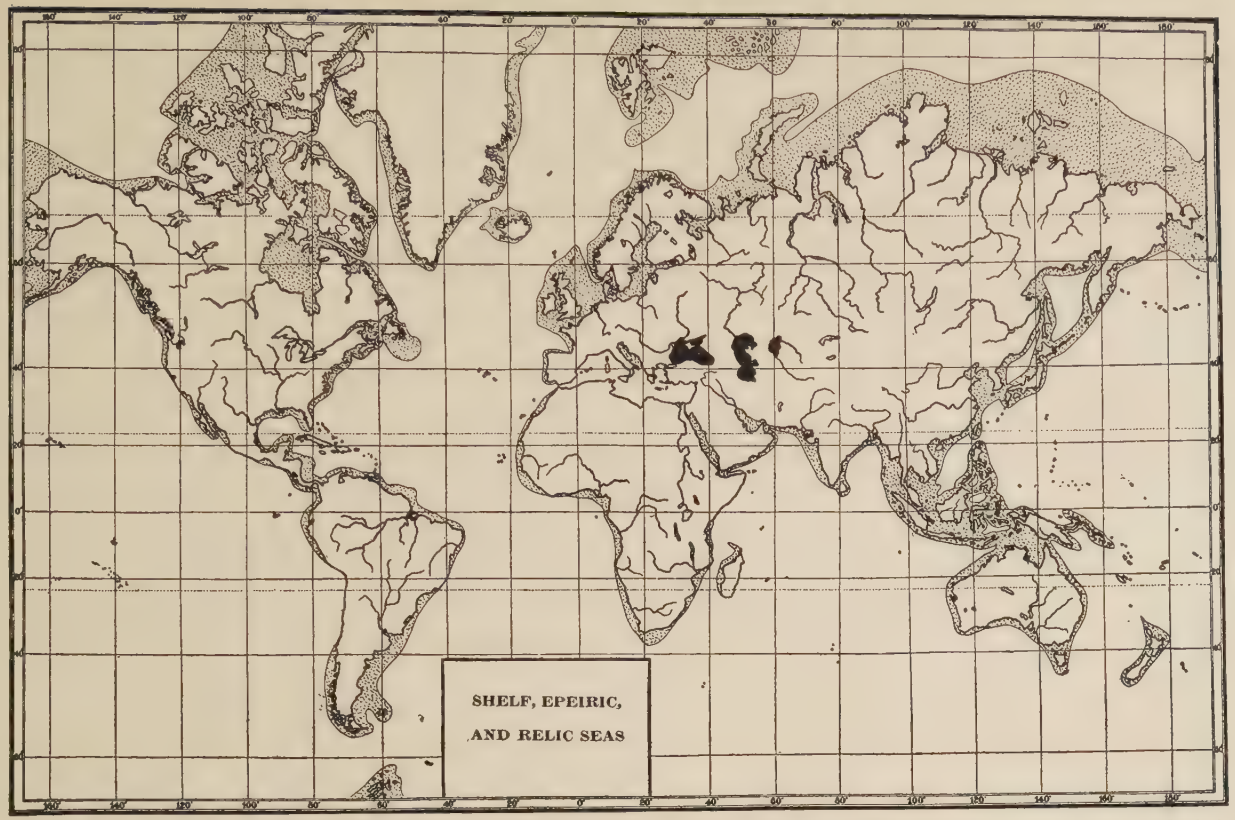


Fig. 334. — Lands (white), seas (dotted), and oceans (white). The areas of the shelf (epicontinental) and epeiric seas are shaded in dots, and the largest relic seas are in solid black.

the shallow marine waters but to those of the fresh waters. As the term " continental deposits " in this sense is now ingrained in Geology, we can no longer use Dana's " continental seas," without raising a question in the mind as to what is meant when their deposits are considered. For this reason we propose here to use *epeiric seas* (meaning seas that lie upon the continents) for the bodies of water that lie within the continents in the downwarps of the continental masses. These areas in times past have experienced great changes through variations of sea-level, sometimes being more or less completely emptied of their water, or filled with sediments and turned into land. Examples of present epeiric seas are Hudson Bay, the Gulf of St. Lawrence, and the Baltic Sea (Fig. 334).

Extent of Seas. — At present the shelf and epeiric seas occupy about 5.1 per cent of the earth's surface, or nearly 10,000,000 square miles, but in the past they were vastly greater, for the North American continent has several times been flooded by epeiric seas that covered from one third to about one half its areal extent. In fact, almost all of Stratigraphic Geology is a study of the sediments of epeiric seas (marine deposits), of fresh waters and of the atmosphere (continental deposits), while it deals little with those of the shelf or epicontinental seas and scarcely at all with the ocean oozes.

Nature of Seas. — The seas are wholly transparent to the sunlight (diaphanous); accordingly, they constitute the only marine area where the bottoms are more or less covered with ground-dwelling plants, and all animals that feed upon such plants are restricted to these waters. As the seas are adjacent to the lands, receive the rivers, and feel the full effect of the waves and tides, it is natural that they should vary greatly in temperature, salinity, agitation of the water, and sedimentation. Since the oceans are mobile, any movement within the earth's mass is reflected by them and causes the seas to become shallower or deeper, or even to be transformed into dry land. Because of these constant changes in the physical, chemical, and organic environment, the epeiric and shelf seas are also the scene of severe struggles among their inhabitants and consequently are the principal arenas of marine biotic evolution. We may then say that the degree of intensity of all these interactions is most marked toward the land and diminishes away from it down the continental slopes.

Effect of Rivers on Sea-life. — Rivers enter the sea through estuaries or deltas, and here the environment of the rivers meets

that of the seas, blotting out most of the marine organisms, and not only piling up the greatest depths of sediments, but also bringing about the most marked variations in sedimentation. Very little of marine life has ever been able to withstand the environment of rivers and so accommodate or permanently adapt itself to fresh water.

Divisions of the Seas

On the basis of their depth and their rock character, we may divide the seas into the strand, the shallow-water littoral, and the deep-water pelitic areas.

The Strand. — All students of the seas are agreed that the strand (the shore or beach) is the most easily defined region, since it lies between high and low tides. In most places the strand is a narrow one, varying in width up to several hundred feet, but where the bordering lands are very flat it may attain to a width of miles. Here the deposits are exceedingly variable in composition and usually coarse in grain, for it is naturally the region of most active wave force. Along the strand we may meet with cliffs, or rivers may bring in gravels, and from either source are formed conglomerates and coarse sands. Conglomerates, as a rule, are of continental origin, but those of the seas either occur at the base of formations, where they are made by waves beating against the cliffs, or are the interbedded gravel deposits brought by the rivers. Where the sea shades into the land may occur the finer sands or muds, which are often rippled, sun-cracked (Fig. 416), or trampled over by the land animals, thus preserving their tracks (Fig. 420). It is very important to bear in mind that sun-cracking is practically restricted to the deposits of the strand and to continental formations (see page 269), for these are the sediments that in the main are exposed to the air sufficiently long to be dried enough to bring about shrinking and tensional cracking. However, there are also areas of the strand, as in the present Runn of Cutch, India (8000 square miles), where marine *playas* (broad mud flats) are bared for months at a time from the sea. It is very probable that the sun-cracked Paleozoic water-limestones of the Appalachian region were formed in this way.

The nature of the strand deposits is, however, dependent not only upon the topography of the land and the proximity of the rivers, but equally upon the climate and the waves and currents that are produced by the winds and tides. The winds constantly vary in intensity and shift in direction, and with them the waves

and currents, bringing about, in the "sea mills" thus formed, a reduction in size of grain, an assorting of rock according to mass and specific gravity, and a drift of material now in this direction and now in another. However, the materials of the strand are usually not in thick deposits and the marine conglomerates are as a rule under 10 feet, though they may attain locally to 100 feet.

Life of the Strand. — The strand is also the *amphibious region*, for sometimes it is a part of the dry land and again it is under the sea. For this reason its life is a peculiar one, highly adapted to an environment that is neither wholly of the one nor the other region; nevertheless most of the organisms are of the sea. When the tide is out they do not feed and most of them are buried in the wet ground, hidden beneath the rocks, under the seaweeds, or in pools of water. The kinds of animals that are actually restricted to the strand are not many, for most of its dwellers are forms that also live in the adjacent region of permanent water.

Littoral Seas. — Below the strand is the *littoral region*. Some use this term in place of strand, and still others include in it the entire depth of the seas. The Latin word, *litoralis*, means *belonging to the seashore*, and in this book we shall so use it, but continue the region from the lower limit of the strand to a depth of 150 feet, the latter point being chosen because at this depth *most* of the assorting power of the waves and their undertow ceases. The littoral region therefore merges landward into the strand and seaward into the deeper waters or pelitic seas. The waves of these shallow waters are most powerful and push the coarser material landward, piling it up toward the strand, while the finer substance is dragged seaward. The sediments, like those of the strand, are exceedingly variable, running from conglomerates to clean, coarse, shifting sands, dirty sands that consolidate and do not shift, and coarser muds. The offshore portions of delta deposits are also laid down in these depths and their shifting sands are dominantly rippled and occasionally cross-bedded. These littoral deposits, due in the main to the inflowing of the rivers, are apt to have remains of land animals and more especially of land plants, such as leaves, stems, and wood, objects far less prevalent in the deeper water deposits. It should, however, be said that but little vegetable matter is entombed in the deposits of the warm littoral waters of the tropics, for the great drifts of timber can only be preserved in temperate and colder waters.

As the storm waves act with some force to depths of about 150 feet, we see again why the littoral region is marked by conglom-

erates, by sands that are rippled, and often more or less cross-bedded, and by quick alternations of sands and muds, both vertically and horizontally; in a word, it is more than any other the region of heterogeneous deposits. Ripple-marks have been seen and measured in depths of 75 feet with the ridges still 3 inches apart, and fine sand has been thrown on the decks of ships where the waters were 150 feet deep. Therefore, great storm waves can lift and rework the littoral bottoms, break up the muds into tabular fragments or roll them into mud-balls, and in this way make the well-known *intraformational conglomerates*, so called because the fragments of which they consist are of the same deposit and age as the rocks in which they lie, and are not of foreign rocks, as is the case with the ordinary type of conglomerates.

The littoral region is also marked by *banks*, those flat shallow-water areas far out from land, such as form the great fishing ground to the south of Newfoundland and to the east of the Maritime Provinces of Canada. These banks are due in the main to currents that have piled up sand and muds; it is, however, not only the currents that do this work, for, as explained on page 40, sea-water rapidly precipitates the muds brought into the sea by the rivers. Thus all the coarser terrigenous material is dropped in the littoral, and only the finest particles are carried by the lessened currents into deeper waters.

To the tropical waters of the littoral region are restricted the great coral reefs, and consequently, with the assistance of the lime-secreting seaweeds and the denitrifying bacteria, these and the adjacent deeper waters are the areas of greatest limestone making. Here also in the shallow waters are formed the calcareous oölite deposits. In the temperate and cooler waters the reef corals are absent, and even though calcareous algæ are present they are of other kinds which are far less effective as makers of limestone. In the same waters but in depths between 35 and 90 feet are found those green seaweeds with wide and fluted blades that are yards in length, known as Laminaria. Growing in great tangles they form miniature forests and are characteristic of the *Laminarian zone*.

It is a well-known fact that *pure sandstones are poor in fossils*, but, when mixed with clay and more especially when limy, do contain them, sometimes in considerable abundance. This is because clean sands are laid down well within the zone of wave agitation, which not only washes out the mud and carries it farther oceanward, but also shifts the sand. Such places have no seaweeds living on

the bottom, and are generally unfavorable habitats for life because of the shifting nature of the deposits and the grinding action of the sharp sands on the organisms. Further, the porous sands permit circulation and solution and have no diffused lime to protect the shells from such dissolving action. It is, therefore, in limy sediments that fossils are most abundant. The subject is referred to again later in this chapter (under diagenesis).

Deep-water Pelitic Seas. — Beyond the littoral seas are the deep-water pelitic seas, which include all the waters of the continental shelves and the epeiric seas from about 150 to 600 feet. The word *pelite* is much used in the study of rocks (Petrology), and in the main refers to fine-grained mud rocks; in connection with the seas the word, therefore, is intended to have reference to the widely uniform and fine-grained character of the deposits of these deeper seas. To these depths the storm waves generated at the surface rarely reach, sufficing only to stir the fine mud which is carried thus far from land, but in most places there is some movement of the waters due to the tidal and oceanic currents. Here also the green seaweeds become less and less abundant with depth, while the brown and red algæ are generally the forms of the deeper waters. On protected coasts, however, the continental slope into the oceans begins at 300 to 400 feet of depth, owing to the lessened wave action.

The deposits of the pelitic seas are the well assorted and widely spread fine sands, and the sandy, clayey, and calcareous muds, along with greater accumulations of organic débris. It should, however, be understood by the student that sedimentation in the deep-water seas is dependent not only upon their currents, but also upon the height of the adjacent lands and the nature of their climate (whether warm or cold, dry or moist), upon whether the rocks are soft strata or hard crystallines, and upon whether the land is clothed with vegetation or is a desert. These general tendencies are further altered by the currents, so that locally even the pelitic seas have deposits that are characteristic of the littoral seas.

Origin of Concretions in Pelitic Seas. — Where cold and warm water currents impinge on one another they are shifted from time to time by strong winds, and in such regions it occasionally happens that the cold shore waters are blown far into the areas of the deep-water seas, killing off many of the warm-water animals. Such an area occurs off the New England States, where in 1882 almost all of the fishes and other swimming animals were killed. The carcasses eventually fall to the bottom and form nuclei which

in their decomposition set up the formation of concretions that are often phosphatic. Similar beds of concretions are also met with in the ancient deposits.

Relic Seas and Lakes. — Peschel in 1883 directed attention to the great bodies of fresh, brackish, or even highly saline waters now completely cut off from the mediterraneans and oceans, but whose present life shows clearly that they were once in open connection with them. The best-known examples of these severed bodies of marine waters are the Black Sea and the Caspian Sea, both of which were once widely connected with the Roman mediterranean (Fig. 334). These seas are therefore marine relics of the past that have gradually been freshened through the inflow of rivers. In the same way we speak of *relic faunas* or *relic species*, meaning that they are relics which have adapted themselves to their present fresh-water or brackish-water habitats, the relic seas (see pages 73 and 79).

The Caspian Sea is the largest land-locked body of water, with an areal extent of 170,000 square miles. Its surface lies about 83 feet below sea-level, and in the north it is very shallow, though in the south it attains to a depth of 3190 feet. It has now no outlet and its waters are removed by evaporation as fast as they are received. Formerly it was a vast inland mediterranean with epeiric connections extending to the Arctic Ocean and the Roman mediterranean. The fauna is a deficient one, but the fishes are so abundant that the fisheries are the equal of those of the northern Atlantic Ocean. Sturgeon are exceedingly common, and the Caspian is also the source of the famous Russian caviar and of isinglass. Other marine animals found in this sea are salmon, herring, porpoises, and seals.

American examples of relic seas and lakes are Lake Ontario and more especially Lake Champlain. Squids are still present, though rare, in Lake Onondaga, once a tributary of Lake Ontario, while the best demonstration that Lake Champlain is a relic sea is seen in its elevated beach deposits of very recent origin (Pleistocene), which have an abundance of marine shells and the bones of seals and whales.

Stagnant Sea Areas. — In the shallow parts of the oceans and in all seas there are large and small areas where the waters are stagnant, and because of the lack of currents the animals living on the bottom, the benthos, soon consume all of the free oxygen that has been absorbed in the main from the atmosphere. Such bottom waters are said to be "stale," and they are taken possession of by sulphur-making bacteria which feed upon the micro-organisms and other life

that falls from the sun-lit, oxygen-absorbing surface zone. As the result of the bacterial life processes, the bottom waters become more and more foul through the liberation of sulphuretted hydrogen gas.

On the other hand, where the prevailing winds are strong toward the land, there is developed a marked seaward undertow that sweeps the bottom clean of deposits and of the organic products of decomposition from the abundant life of the littoral seas. The material gathers in the currentless depressions of the pelitic seas, where it accumulates as black mud. Such *dead grounds* are known in many seas. Others, such as the submarine channel of the Hudson River, are known as *mud holes*. The abundance of organic matter colors the muds blue-black to black and they abound in petroleum and in sulphide metals, usually iron pyrite. Many formations of this kind are known in Geology, and some of them have a petroleum content as high as 20 per cent.

Walther says that as long as a part of the seas is in open circulation with the ocean and its waters are constantly interchanged and the normal salinity maintained, there will live and be continued a normal marine fauna. As soon, however, as the free circulation of the water ceases, as in a quiet bay or between islands of an archipelago, all normal conditions are altered. Such stagnant places are characterized by accumulations of organic matter, by the development of poisonous sulphuretted hydrogen gas in the water, and by the vanishing of bottom-living organisms. Only the floating and swimming organisms or drifted plant material attain these quiet places, where they are often wonderfully conserved in the muds. This detailed preservation is well known in America, for in the black shales at Banff, Canada, and Rome, New York, we have examples of trilobites retaining the antennæ and limbs in an extraordinary state of preservation.

Mud Bottoms. — As a rule the areas of mud accumulation are devoid of attached seaweeds and, since the water currents are here very slight, little food is brought to the animals that might otherwise live upon or in the mud. In consequence the mud areas have a scant life and are therefore known as the *desert areas of the seas*. These observations of the present marginal seas also help us to understand the dearth of life in the majority of the green, blue, and black shale deposits of epeiric origin. When fossils of bottom-dwelling types do occur, they are in thin zones and more often swimming or floating forms.

Sediments and Their Alteration

Kinds of Sediments. — In general it may be said that the sediments of seas are coarser in grain than the oceanic deposits, but of finer grain and far better assorted by the moving waters than the continental formations. The sediments of all strata are either

mechanically formed or of *organic origin*. The former embrace the *arenaceous deposits* such as the sandstones and sandy shales which together make about 15 per cent of the water-laid strata, and the *argillaceous deposits*, the mudstones, which constitute about 80 per cent of the sedimentaries (F. W. Clarke). The *organic deposits* make up only 5 per cent of the water-laid strata and consist of limestone, dolomite, chalk, marl, and the oceanic pelagic oozes. What percentage of the muds and organic deposits is permanently lost by the continents and added to the oceanic basins is unknown.

Deposition of Limestones and Dolomites. — The lime and magnesia carried in solution by the rivers to the seas are distributed far and wide by the marine currents. That small part which is taken out of the water through organic agency in the littoral is masked because of its dissemination through the thick deposits of these seas. For this reason it is usually said that limestones and dolomites are the deposits of the deeper waters and those far from the shore. However, back of the Keys of southern Florida, where the waters are warm and the land is limestone and but little above sea-level, limestone and oölite deposits may be seen accumulating on the very shore. In the past few years it has become plain that the main areas of limestone and dolomite formation are the warm waters, for in the tropical regions not only do the rivers bring to the sea more lime, but the oceans are also far richer in denitrifying bacteria (Fig. 335) and it is these micro-organisms that in their physiological processes throw down the main amount of lime carbonate. To this are added the structures made by the lime-secreting algæ, of which there are many kinds, by the coral reefs, and by other lime-using animals. The calcareous muds in the deeper water of tropical and subtropical regions, in depths of from 600 to 2000 feet or even more, have from 80 to 90 per cent of lime, and of this from 10 to 50 per cent originates in the floating Foraminifera, while from 2 to 40 per cent is from bottom-living Protozoa. Proceeding poleward we meet with less and less of limestone accumulation, though this is always locally dependent upon the temperature of the surface waters that again are so largely altered by the great oceanic currents.

Fig. 335. — The bacteria that cause the precipitation of calcium carbonate in the ocean (*Pseudomonas calcis*). Greatly enlarged. After Kellerman and Smith.

Nansen has directed attention to the hemipelagic muds of the central Arctic Ocean, which he says are devoid of large organisms and are brown in color, with only from 1 to 3 and rarely 5 per cent of lime. He states that this mud is a mineral deposit devoid of life other than a few bottom-dwelling Foraminifera. The muds of the Arctic waters off Europe show far more lime, from 25 to 40 per cent, with a maximum off Iceland of from 45 to 60 per cent, dropping at Jan Mayen again to 10 per cent. Most of this lime is from Foraminifera (*Biloculina*). It would further appear that more lime is present in the surface muds than in those beneath, an increase that may be due to the gradual warming of the climate in recent geologic time.

Diagenesis. — As limestones are of organic origin, naturally they should have an abundance of fossils, and most of them do. It is well known, however, that many are more or less crystalline, as are nearly all of the dolomites, and in this case fossils are usually absent or are so altered as to be almost unrecognizable. Here we are not dealing with metamorphism, because many such limestones and dolomites still remain horizontal and occur in areas unaffected by elevation and igneous injection. It is true that a process of alteration has taken place, but it was contemporaneous with accumulation and not ages afterward. The diagenetic changes are due to chemical alterations taking place on the sea bottom and in warm waters. The Globigerina oozes of the present seas show no alterations and, even though they are the *growth* of warm surface waters, are accumulated in the ice-cold depths of the ocean abysses. The limestones of shallow warm waters, as for instance many coral reefs, have lost most of their organic structures, and we learn by careful study that the carbonate of lime originally present in the form of aragonite has been converted into calcite. In addition, the original carbonate of lime in either form may be more or less replaced by magnesium carbonate and thus a calcium carbonate coral reef may be altered into a dolomite. Time, warm water, variable concentration of solutions, much oxygen, and a wealth of decomposing organic matter are the requisites that will completely alter calcareous organic accumulations into crystalline limestones and dolomites. This alteration has been called by Walther *diagenesis*, from words meaning *through* and *birth*, or, in other words, it is a rebirth through contemporaneous alteration.

Iron pyrite and marcasite concretions and fossils of black shales are also diagenetic products. Moreover, it has been held that the flints of chalk deposits are diagenetic in origin where the colloidal silica of sponges is progressively dissolved and redeposited about nuclei as flint and thus converted into these irregular lumps. On the other hand, the cherts of limestones develop near the surface in

the zone of the circulating ground waters during the process of weathering, and are therefore not of diagenetic origin. As chalk is porous to ground water, and as the flints occur in both horizontal and vertical attitudes, it is probable that they, too, are formed after the sediments are uplifted sufficiently high to permit the circulation of meteoric waters.

CHAPTER XXIV

EVOLUTION OF THE STARS AND THE SOLAR SYSTEM

Stars Seen by the Naked Eye. — What a wondrous sight are the skies on a clear dark night, especially in the rarefied air of a mountain top or in the dry climate of the desert! We see distinctly hundreds of quivering stars, large and small, variable in color, all set in the deep black of boundless space. The Milky Way extends across the whole sky like an irregular filmy cloud of silvery white, and it too consists of stars in various stages of their careers. The largest of all the apparent stars are, of course, best seen in the early evening and morning — Evening and Morning Stars, as we call them, though they are not stars but planets of our solar system shining by reflected light derived from the sun.

All of the true visible stars are self-luminous bodies and most of them exceed by far the dimensions of the sun, although the latter has a diameter of about 864,000 miles. This life-giving sun is the nearest star, and yet, though its rays reach the earth with considerable warming power, it is about 93,000,000 miles away. The nearest fixed star, on the other hand, is more than 200,000 times more distant than is the sun; nevertheless most people can see at any given locality at least 250 stars, and good eyes can make out about 800. In all that portion of the sky visible from the northern United States about 1600 stars can be discerned with the unassisted eye.

Stars of Astronomers. — The astronomers, however, by means of their marvelously delicate telescopes, spectroscopes, and photographic cameras, estimate that they have records of nearly 114,000,000 stars, and still this is by no means all, for as their apparatus is perfected more and more, the greater will be the depth to which they can penetrate into space and the greater the number of stars they will discern. There are also scattered through the heavens many dark stars, invisible because non-luminous, the approximate number of which no one knows, nor have we any knowledge of their planets and satellites, if such they possess. Space without limit, through which are moving countless systems of orbs in wondrous array — such is the majesty of the Universe!

New Stars. — It is known that all the stars are in motion in various directions, our sun with its retinue of planets moving toward Vega at the rate of 11 miles per second. This being so, why is there not the possibility of collision between the stars or between them and the unknown dark orbs, or at least an approach so near as to result in disruptive tidal strains?

Every now and then there suddenly appears in the sky, and mainly in the region of the Milky Way, a *nova*, a new or temporary star that lasts but a short time. It is the record of "a superb stellar catastrophe." Temporary stars have blazed up about twenty-six times since men began to write their records of the skies. The most famous is Tycho Brahé's star of 1572, which reached a brightness greater than any other star, but which, notwithstanding its brilliance, remained visible but sixteen months.

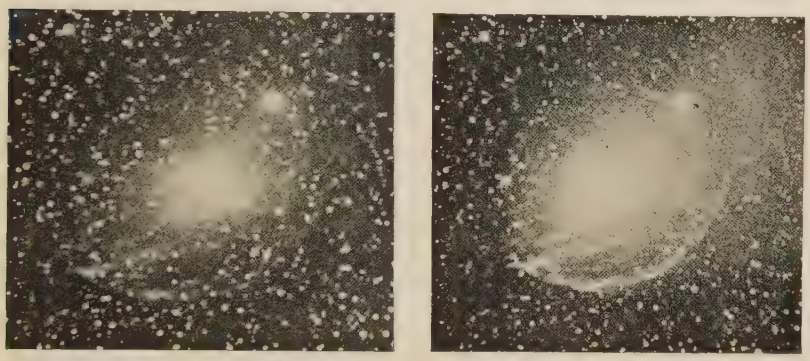


Fig. 336. — The new star in Perseus in 1901, showing expansion of nebulosity from September 20 to November 13. Photograph by Ritchey, Yerkes Observatory.

One of the most wonderful astronomic objects ever observed was seen in the constellation Perseus on February 22, 1901, when photographs made twenty hours apart showed a new star present only on the plate last exposed. The actual birth of the star, however, must have occurred about 1781, since it would take approximately 120 years for its light to reach the earth. Within a few days after the discovery of this star, its brightness grew to the first magnitude, and while it was fading it developed into a nebulosity (Fig. 336).

Stellar Evolution

Origin of Stars. — The light of the stars, when transmitted through the prism of the spectroscope, shows that their temperatures and the nature of their elemental matter vary enormously.

Stars apparently begin in nebulous matter, and it has been said that the nebulous clouds are the matrices, the primitive and uncondensed material out of which stars are made. As stars they are in the gaseous state, and further evolution takes place, through condensation and the loss of heat by radiation, into smaller, more complex, and hotter suns. It is thought that they will pass eventually into invisibility as dark orbs with cold exteriors.

The great nebula in Orion (Fig. 337) is thought to be in the first period in the history of a star, for here the gas is exceedingly

Fig. 337. — The great nebula in Orion, with irregular star condensing centers. Photograph by Ritchey, Yerkes Observatory; two-foot reflector, one-hour exposure.

tenuous and the stars condensing in it seem to indicate that the entire cloudlike nebulous mass is also in motion. From this primitive astral condition we pass to the

Helium Stars. — The spectroscope has brought out the fact that the spectra of stars increase in complexity as the cooling process continues. Through the study of the spectra it has been

learned that the gaseous nebulæ of the Orion type in their earlier development reveal dominantly helium.

Hydrogen or Sirian Stars. — Next in order of evolution, according to Hale, appear to be the white, or bluish-white, stars like Sirius, in which the spectrum is marked by conspicuous hydrogen lines, associated with inconspicuous ones of iron, sodium, magnesium, etc. These stars, though relatively condensed, are, however, much less dense than the sun. As the gaseous masses condense they lose through radiation a vast amount of heat and, surprising as it may seem, grow hotter. This is true so long as the star remains gaseous.

Solar or Metallic Stars. — Further condensation produces more and more of a thick absorbing atmosphere, and the consequent

Fig. 338. — Solar prominences during the total eclipse of May 28, 1900. Photograph by Barnard and Ritchey, Yerkes Observatory.

filtering of the stars' light causes them to take on a yellowish or reddish tinge. The hydrogen or Sirian stars previously noted do not possess dense absorbing atmospheres, and due to this fact and to their extremely high temperature, they are revealed to us as the white or bluish-white stars. Solar or yellowish stars, on the other hand, are thought to have attained stellar maturity, and like the sun have thick absorbing atmospheres; their interiors, however, are still gaseous, though under strong compression. The sun is one of the metallic stars, somewhat hotter than the reddish yellow or Arcturian type, and the spectroscope reveals in it the presence of vapors of iron, sodium, magnesium, calcium, hydrogen, and many other substances known on the earth. The sun is

therefore a star practically identical in chemical composition and in physical constitution with many other stars in the heavens.

Hale describes the appearance of the sun at times of total eclipse as follows: "Red flames, sometimes reaching heights of several hundred thousand miles, may be seen rising from a continuous sea of flame, which completely encircles the Sun. [They shoot outward with velocities of hundred of miles per second. See Fig. 338.] These are the prominences, and the continuous mass of flame from which they rise is the chromosphere. Extending far beyond these flames into space, sometimes to a distance of millions of miles, is the corona, which shines with a silvery luster somewhat inferior in brightness to that of the full Moon."

Helmholtz calculated that the sun's heat could be supplied by the shrinkage of its vast bulk under the influence of its own gravitational attraction. An annual shrinkage of only 300 feet in the solar diameter would be transformable into enough heat energy to maintain the observed radiation. This energy of the sun is conveyed through the ether of space and attains the earth in eight minutes and twenty seconds, or at the rate of 186,000 miles per second.

Carbon or Antarian Stars. — The stars in their continued evolution beyond the solar stage eventually fade further and further toward invisibility. From the yellowish stars we pass to those of an orange or red color, the spectra of which reveal marked carbon lines. The latter is the last period of stellar visibility.

Dark Stars. — Finally the evolution continues into the dark or invisible stars, of which many are known to exist by the gravitative disturbance which they exert upon the neighboring stars. The last stage will be the formation of a hard outer shell, but no life will be evolved because there will be no light to supply the necessary environment for organisms. The original motion, however, will continue, and therein lies the possibility of a future cataclysmic approach to some other star.

Nebulæ

Number of Nebulæ. — These luminous clouds of matter are strewn in space less thickly than the stars, and though enormous in size but two can be seen by the unaided eye (Orion and Andromeda). The largest is the great nebula of Andromeda, hundreds of thousands of times greater in diameter than the distance from the earth to the sun, yet visible only on the clearest of nights, due to its extreme tenuity and tremendous remoteness. Hale says it is the most interesting object in the heavens.

Keeler estimates that within the reach of the Crossley reflecting telescope fully 120,000 nebulæ will be revealed, with photographic assistance, and Poincaré states that eventually astronomers will know more than a million nebulæ.

Nature of Nebulæ. — Nebulæ are filmy masses of shining gas, with or without diffused solids, and possess an inconceivable tenuity; in fact they are almost without any density whatever (Figs. 337, 339–341). They are thought to be in a state of change, condensing with extreme slowness into nebulous stars or clusters of stars. In some, no condensing centers are seen at all, and they then appear as the thinnest fleecy clouds, but in most of them occur one or more brighter though hazy nuclei. There are a number of fundamentally distinct kinds which may be discussed as follows:

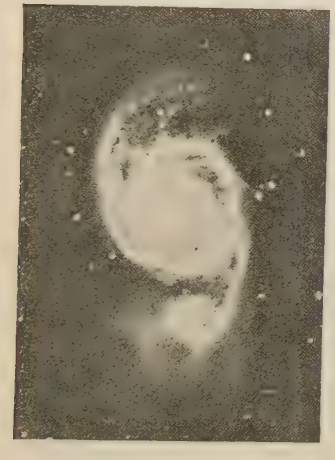


Fig. 339. — A brilliant spiral nebula in Canes Venatici. Photograph by Ritchey, Yerkes Observatory; two-foot reflector, six-hour exposure.

Fig. 340. — A typical spiral nebula in Pisces. Photograph by Lick Observatory.

Green Nebulæ. — The rarer of these gaseous and luminous masses are known as the green nebulæ, nearly all of which are found in the Milky Way. They are characterized in the spectroscope by bright lines, the brightest of which are green in color and represent nebulium, an element known only in these nebulæ. Other lines indicate hydrogen and helium, but no metals seem to be present. The cause of their luminosity is unknown, and is probably not heat; their temperature may be near absolute zero. As the green nebulæ appear to have no direct bearing on the evolution of the solar system, they need not be further considered.

White or Spiral Nebulæ. — The greater number of nebulæ, however, are known as the white nebulæ, because their white light gives continuous spectra (Figs. 337, 339–341). The material, though solid, Chamberlin conceives to be in a finely divided condition.

The cause of the white light is unknown, and opinions differ as to the elemental constitution of these nebulæ.

The dominant and possibly even the universal form of the white nebulæ is the spiral, and they are therefore referred to also as

Fig. 341. — A spiral nebula in Ursa Major. Photograph by Ritchey, Yerkes Observatory; two-foot reflector.

the *spiral nebulæ*. The one in the constellation of Andromeda, as has been said above, is the greatest of them all. " From the superior number of spiral nebulæ it is a safe inference that their pecu-

liar forms represent some prevalent process in celestial dynamics. This is, in itself, a reason why research should turn to them by preference for the origin of the present solar system." (Chamberlin.)

The significant feature of these nebulæ is the presence "of two dominant arms that arise from diametrically opposite sides of the nucleus, and curve concentrically away. . . . There are often more than two arms in the outer part, and there is much irregularly dispersed matter." Throughout the mass, but more especially on the arms, are partial concentrations of matter spoken of as the *nebulous knots*, while otherwise the diffuse nebulous matter is unequally distributed. We seem to see here independent parts revolving about the common center of gravity, as though they were planetoid bodies, and Chamberlin goes on to say that if this were certainly known to be the case, they might well be called *planetesimal nebulæ*. The importance of this interpretation will be seen later.

The tenuity of these nebulæ shows that they are thin and disc-shaped and that the matter is also irregular in distribution within the discs, all of which conforms to the mode of distribution of matter in the solar system.

Meteorites

We must here digress a little to study the meteorites. On almost any dark night, but more especially during August and September, may occasionally be seen brilliant white or green streaks of light shooting with high velocity and in diverse directions through the skies. These fiery lines, popularly called "shooting stars," are caused by bodies of solid matter varying in size from a fraction of an ounce to a hundred or more tons, but averaging about the size of a grain of wheat (Figs. 342, 343). They are moving swiftly through space and have come into contact with the atmosphere of the earth. The velocity of impact is so high, averaging between 20 and 30 miles per second, that the meteors are heated to the point of dissipation as a luminous gas by the friction generated in passing through the terrestrial atmosphere. Thus they become visible only at the moment of their dissolution, and this is dependent upon the accident of collision with the earth.

On certain nights of the year and especially in certain years, the number of meteors is enormously increased, and they appear to radiate from some one part of the sky like a rain of shooting stars. At such times the earth in its motion around the sun is passing

through a swarm of meteors also moving together about the sun. Such a swarm is called a meteoric swarm.

Meteorites are wanderers from other solar systems attracted to

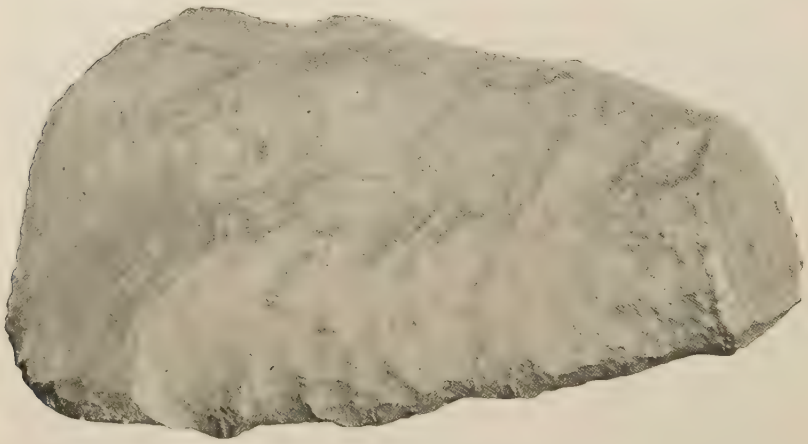


Fig. 342. — The Gibbs nickel-iron meteorite found in Texas. Weight 1635 pounds. At Yale University.

Fig. 343. — A stony meteorite that fell at 5 P.M. on May 26, 1890, in Winnebago County, Iowa. In exploding it broke into several thousand fragments, more than eight hundred of which are here shown. The largest piece weighed 80 pounds. At Yale University.

the sun and earth from outer space. They bring to us samples of the bodily constitution of the former and the proof that they are closely related in their chemical elements to our own sun and

earth (Figs. 342–344). For the relations of meteors to comets see the next chapter.

Chamberlin regards meteorites as "but an incidental result of stellar and planetary action. Their genesis is wholly a secondary matter, and furnished no ground for regarding meteorites as the parent material of great nebulæ or of stellar systems. . . . This scattered matter is presumed to be picked up bit by bit by all the larger bodies, as is being done daily by the earth."

Fig. 344. — Section of the Grand Rapids, Michigan, meteorite, showing the coarse crystallization of the nickel-iron (Widmanstätten figures). Natural size. At Yale University.

There is a great variety of meteorites, but the larger number of falls center around two main types: (1) the common nickel-irons, often of great weight (Figs. 342, 344), and (2) the rarer and usually smaller chrondritic or stony meteorites (Fig. 343). Their micro-structure shows their crystalline aggregates or chondri to be usually fragmented or brecciated. There is also an absence of water and hydrates, free oxygen, quartz, orthoclase, mica, etc., but they show the presence of volatile and combustible hydrocarbons, and of certain unstable chlorides, sulphides, and phosphides unknown on the earth.

Theories of Solar Origin

Man, with all of his limitations, has throughout long ages been asking whence came the earth, his home, and the sun and stars in the canopy of the heavens above it. It is only within the past few centuries, however, that this inquiry has been pursued along scientific lines, and among the older peoples "the limit of the spiritual field of vision determined the wider or more circumscribed flights of imagination."

The downfall of the Roman Empire and the long succeeding

periods of constant warfare, along with climatic changes, prevented all far-reaching philosophic endeavors during the first twelve centuries of the Christian era. The next expansion in the realm of thought came with the revival of learning that spread throughout Europe in the fifteenth century, when universities, learned societies, and academies were founded. Then methods of dogmatism were cast aside and the modern scientific methods of attaining knowledge took their rise.

Nebular Hypothesis of Kant. — Astronomy and physics received a great impetus from Newton's principle of universal gravitation, given to the world in 1687, a principle that led to a sound conception of the evolution of the solar system. This Newtonian principle was the basis of Emmanuel Kant's nebular hypothesis, which that professor of mathematics and physical geography at Königsberg presented in 1755. His *Naturgeschichte des Himmels* appeared anonymously and remained in oblivion for ninety years, to be finally unearthed from neglect by Von Humboldt.

Kant, according to Iddings, conceived that the universe might have been developed out of chaos and that space was filled with fundamental material highly varied as to mass, density, and power of attracting other particles. He argued that since the planets and their satellites moved in strict conformity with one another and in definite relation to a central sun, with vacant spaces between them, there must have been a diffusion of their substance through space, and a subsequent segregation into planetary masses.

The attraction of the particles for one another would occasion motion in all directions throughout the swarm. The denser would in time become nuclei of condensation. Finally there would thus result zones or rings of discrete particles segregating into condensing nuclei, which upon further condensation become planets and satellites, the preponderating central nucleus becoming the sun.

Heat, he held, was formed through cosmical attraction according to laws that are chiefly chemical, and gases on condensation liberate heat. The amount of heating must be proportional to the mass of the growing body, and to the rapidity at which the mass condensed. Consequently the greatest heat would be in the central body or sun.

Nebular Theory of Laplace. — The nebular hypothesis was again independently developed by the Frenchman, Laplace, in 1796 and further modified in 1824. This celebrated explanation of the origin of the solar system, as Hale states, has dominated the world's thought since the very date of its publication. Iddings has re-

studied Laplace also in the original and from his work has been taken the following:

Laplace imagined the planets and satellites, because of the similarity in their rotations and in the planes of their orbits, to have been derived from some vast fluid of immense attenuation which surrounded the sun like an atmosphere and extended beyond the outermost planet, Neptune, a body 2,800,000,000 miles away from the sun. This nebulosity was supposed to have possessed a high temperature, and was so attenuate that one may scarcely conceive of its existence. It revolved about the central nucleus

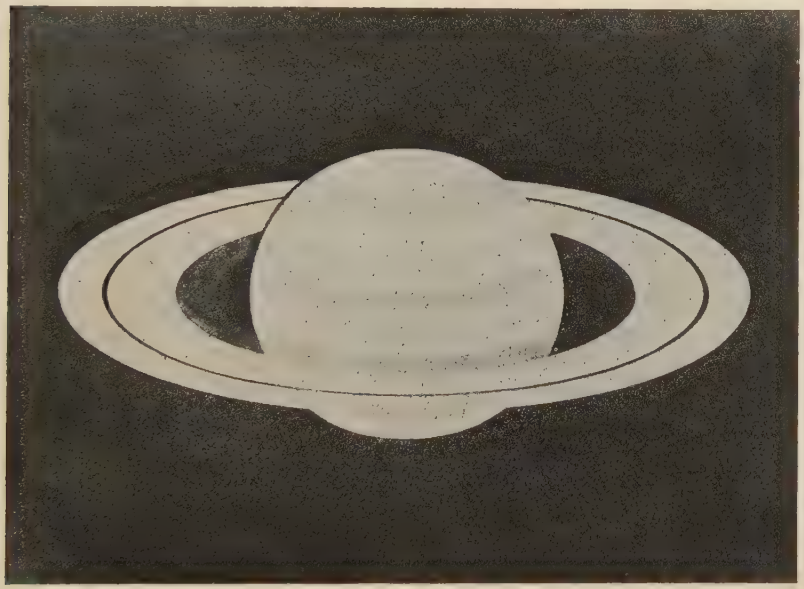


Fig. 345. — Saturn as seen with the 36-inch refractor. Drawing by J. E. Keeler, Lick Observatory. The outer ring has a diameter of 172,610 miles, a width in its plane of about 11,000 miles, and a thickness estimated at 50 miles. The space inside the outer ring is 2200 miles, and the second ring is about 18,000 miles wide. The dark or crape ring is about 11,000 miles wide, with its inner edge less than 6000 miles from the surface of the planet. The equatorial diameter of the planet is 76,470 miles. (Moulton.)

or sun and assumed a disc-like form. In the course of time it successively gave rise to equatorial zones or rings, resembling those of Saturn (Fig. 345), and these rings segregated into nuclei and eventually condensed into planets. In their turn the planets condensed and repeated the process of annulation, thus giving origin to the satellites. In the case of the planetoids, the very small planets also

known as minor planets or asteroids, the masses of the broken rings did not unite into a planet, but each part formed an asteroid. On the other hand, some of the rings of Saturn did not break but remained as rings. To account for the eccentricities in the orbits and their deviations from one plane of revolution, he imagined that there were numberless variations in the temperature of different parts of the nebula and in the densities of the nuclei, that is, it was a nebula that was clearly heterogeneous both as to density and temperature. He conceived of the earth as having passed from a gaseous to a liquid, and finally a solid condition, with absolute rigidity.

Objections to Laplace's Theory. — Even though the nebular hypothesis of Laplace has so long dominated the world's thinking, objections and difficulties were brought forward at various times during the nineteenth century. According to Barrell, we may divide these into *fundamental objections* and *modifying objections*. Of the fundamental ones, perhaps the most readily appreciated is that concerning the energy of rotation of the system. This and others have been developed by Moulton, who worked with Chamberlin upon the larger problems of earth origin. The argument as developed is briefly as follows: If the mass of the solar system at one time revolved as a unit and at the same time condensed, toward the center it would gain in angular velocity of rotation, as is seen when agitated water converges toward the central part of an eddy. By virtue of such condensation and angular acceleration, the equatorial belt of the nebula would at last reach a critical state when the outward or centrifugal force balanced the inward gravitative force. After this stage was reached, the matter could no longer converge toward the center, but would be left circling in space about the center. The remainder would continue to condense, but more and more would reach the critical equatorial velocity and be left behind. Yet contrary to this expectation, the bulk of the planetary matter and by far the greatest part of the rotational energy of the solar system about the solar axis resides in the giant planet Jupiter. All of the interior or minor planets, among which the earth is included, are negligible in comparison.

Most telling of all, however, in this line of argument, is the slow rotation of the sun itself. Instead of being a swiftly revolving and highly oblate body, with its equatorial zone in a critical gravitative condition, it revolves leisurely once in twenty-five days; so slowly, in fact, as to have no measurable departure from the spherical form. Now mathematical analysis shows that the *energy*

of rotation of any body in space cannot be increased * or diminished by internal motions. It can be diminished only by a frictional resistance of space or by tidal forces raised upon or within it by some great external body. Neither of these conditions can be invoked. Therefore the matter of the sun revolved with but little energy through all its history, and the antecedent solar nebula, if it included the planets, could never have revolved as a unit. Hence the matter of the planets, even before their aggregation, revolved separately from the sun. It is difficult, then, to regard them as left behind in the primordial contraction of the solar matter from a widely diffused nebulous state of which the planets were a part.

To appreciate fully all the arguments that bear against the Laplacian hypothesis, Chamberlin and Salisbury state that the student must have a knowledge of celestial mechanics and of the molecular activities of gases. Because of this difficulty, all of the objections will not be recited here. In addition to the fundamental objections just discussed, the following are taken from Chamberlin and Salisbury and from Hale:

(1) No nebulæ closely resembling the annulated solar nebula have yet been discovered. The type thought by Laplace to support his theory has since been found to be spiral in the great majority of cases. (2) If the original solar nebula extended to the orbit of Neptune it would have been so extraordinarily tenuous as to have made it impossible for separate rings to have formed. In a hot gaseous nebula, moreover, the molecular activities would cause the molecules to separate from the parent nebula one by one. It has also been shown that the original solar nebula may have been a gas or a swarm of meteorites and that its temperature may have been low and not hot. (3) If the planets developed from the ring system as postulated by Laplace, they should rotate in the opposite direction from the parent body, the sun, and this is not their present condition. (4) The satellites should all revolve about their planets in the direction in which the planets rotate on their axes; but the ninth satellite of Saturn revolves in the opposite direction. (5) Phobos, the inner satellite of Mars, revolves about the planet three times while the planet rotates once. The Laplacian hypothesis requires that its velocity should be less than that of the planet's surface. (6) The rings of Saturn are not gaseous, but were shown mathematically by Maxwell in 1859 to be necessarily composed of small bodies like meteorites. Further, the rings do not revolve like solid bodies, as stated by Laplace; on the contrary, the inner parts of the rings are traveling faster than the outer, and each of these swarming meteorites is moving at the velocity a satellite would have at the same distance from the planet. (7) The masses of the various planets, as well as the densities of the rings from which they are supposed to have been formed, are shown to be entirely out of harmony with what the hypothesis would lead us to expect. (8) Even if rings

* Increase of *velocity* due to condensation should be distinguished from increase of *energy* of the rotating body.

had been formed, Moulton has shown that it would have been impossible for the nebular material to draw together into a planet. (9) He has also shown that the diffuse earth-moon ring, with its low power of attraction, could not have held any atmospheric gases or water-vapor. Even such concentrated bodies as the moon and Mercury are now unable to hold atmospheres. See also page 249.

Hale concludes: "It can hardly be denied that Laplace's idea of the development of the solar system must be reconstructed or abandoned."

CHAPTER XXV

ORIGIN OF THE SOLAR SYSTEM UNDER THE PLANETESIMAL HYPOTHESIS

By Joseph Barrell

Survey of the Problem

The logic of all branches of science points to the existence of some system of evolution of the universe, its complete nature hidden in the vastnesses of time and space, but nevertheless developed in accordance with nature's laws.

Nebular Hypothesis. — The achievement of the eighteenth century which expressed man's efforts to find a solution for this great problem was the nebular hypothesis. It measured a vast advance in ideas beyond the ancient and medieval conceptions of the mode of origin of the universe, but, as has been shown, as an attempt to account for the origin of the planets, it meets with grave difficulties when analyzed. It was founded essentially upon the conception of the condensation of matter, originally existing in a diffuse state, through gravitative attraction. A further essential part of the hypothesis was the conception of a nebula as a unit body, distended by heat, and revolving as a single mass.

Distinctive Features of the Planetesimal Hypothesis. — But toward the end of the nineteenth century, some, of more penetrating vision, began to see also the evidences in the stellar universe of prodigious forces of an opposite nature, not those of attraction, but of repulsion. The tails of comets blown away from the sun with high velocity, and the streamers which compose the solar corona, the envelope of the sun, seen only in eclipses, pointed to the repellent forces of electricity and light. New stars, the high velocities of some other stars, and the forms of certain star clusters seemed further to suggest a possible mode of origin through vast explosive and therefore repellent forces contained within the stars themselves. The tides also are the expression of forces which, though weak as shown upon the earth, tend toward the disruption of the bodies upon which the forces act.

The sun and moon raise terrestrial tides by virtue of the pull of gravity and thus modify that spheroidal form of the earth which is given by its own gravity and the centrifugal force of its revolution. Suppose, in other examples of heavenly

bodies, the tidal pull to be many times stronger, the self-gravitative cohesion to be many times weaker. A limit will be reached at which the body may be pulled to pieces. This phenomenon, which has been actually observed in the case of comets passing close to the sun, has been called *tidal disruption*.

It remained for Chamberlin and Moulton to apply the theory of tidal disruption to the explanation of those nebulæ which exhibit a spiral form and to see in this an hypothesis which might explain the evolution of that planetary system to which our earth belongs. This, the *planetesimal hypothesis*, is fundamentally different from the nebular hypothesis in that it supposes as a beginning a disruptive expansion of matter from some central body, an ancestral sun, the planetary matter being conceived as thrown out from a sun and assuming the form of a spiral nebula, not, as under the nebular hypothesis, as being the residue left behind from a primal condensation of matter into a sun. The form of the nebula was, in this new conception, supposed to be maintained through the motion of its particles moving in orbits, and not by the resistance of heated matter to condensation. After being thrown out, however, processes of local convergence came into operation, by means of which the scattered nebulous matter, whose constituent particles may be called planetesimals, became drawn into nuclei. The nebula consisting of planetesimals passed thus into a planetary system. When this stage was reached there began the geologic history as distinct from the cosmic history of the earth.

By the very naming of a scientific conception as an hypothesis, it is to be understood that although therein lies, it is thought, a contribution toward further knowledge, there is still much which remains unknown. The truth must be tested and enlarged by future generations, the conceptions remodeled and separated from the adherent errors. But the value of an hypothesis lies in the degree to which it coördinates and explains a large number of facts, and in the fertility of suggestions which it offers toward new lines of investigation. Judged by these tests the planetesimal hypothesis is the crowning achievement of the nineteenth century in the field of cosmic philosophy.

What then make up the warp of theory and weft of fact which are woven together to make the fabric of this hypothesis?

The Order Among the Planets

Nature of the Planets. — The points of light seen on a starry night are of two fundamentally different natures. The true stars, of all grades of brightness and innumerable to the eye, are distant

and self-luminous suns. They are distinguished by their apparently fixed relations in the heavens through all the centuries, and by the trembling or scintillation of their light as a result of its passage through the terrestrial atmosphere. These qualities are due to their inconceivable remoteness from us, a remoteness which renders inappreciable, except to the astronomer, their really swift motions, and causes their glowing discs, though millions of miles in diameter, to appear as mathematical points of light, the rays from which are momentarily deflected from the eye by the varying refraction due to the slightest motions of our atmosphere.

Contrasted with the *stars* there are five bodies visible to the naked eye which to the casual observer appear as stars, but are in reality of a wholly different nature. These are the *planets* Mercury, Venus, Mars, Jupiter, and Saturn, distinguished by the fact that they wander in a certain pathway through the heavens, the more swiftly moving showing a change of position among the stars perceptible to the unaided eye even in a few nights, while the slower ones show an appreciable shifting only from month to month, or year to year. Their light, furthermore, is clear and steady, owing to the fact that they have appreciable discs, readily visible in the telescope. In spite of the disturbances in the terrestrial atmosphere, light from one or another point of the disc is consequently continually reaching the eye of the observer.

Two of them, Venus and Jupiter, are, except for the sun and moon, the brightest objects in the heavens, but the telescope has added to the number of the planets two large ones, Uranus and Neptune, invisible because of their distance, and, in one zone of intermediate distance, a swarm of smaller bodies, the *asteroids*, better called planetoids. The planets are bodies like the earth and moon. The earth is in fact one of them and the moon is its satellite. All revolve in nearly circular orbits about the sun. In size they sink to vanishing insignificance in comparison with the sun or any other star. Their distances from the sun and from each other are also almost infinitesimal in comparison with the distances which separate the stars. They shine by light reflected from the sun, and as all are attendant upon the sun, they form a common system, the solar system. Their mutual relations are therefore of fundamental significance in the study of those events which led up to the origin of the earth.

TABLE OF THE PRINCIPAL ELEMENTS OF THE SOLAR SYSTEM

The facts regarding their size, their distance from the sun, and the inclination and position of the plane of their orbit with respect to the orbit of the earth are tabulated as follows:

The Solar System.

	Name.	Diameter, miles.	Density, water = 1.	Mean distance in millions of miles from the sun.	Inclination of plane of orbit to earth's orbit.
	Sun	866,400	1.39	.....	7° 15′*
Minor planets	Mercury	3,030	?	36	7 00
	Venus	7,700	4.85	67	3 24
	Earth	7,918	5.58	93	0 00
	Moon	2,162	3.40	0.239†	5 09
	Mars	4,230	4.01	141	1 51
	Planetoids	0 to 485	?	200 to 400	0 to 34 42
Major planets	Jupiter	86,500	1.33	483	1 19
	Saturn	73,000	0.72	886	2 30
	Uranus	31,900	1.22	1782	0 46
	Neptune	34,800	1.11	2792	1 47

* Inclination of sun's equator to earth's orbit.

† Mean distance of moon from earth.

Notable Planetary Relations. — That the orderly nature of this system implies some mode of evolution was seen by the framers of the nebular hypothesis. The more notable of these relations, following the summary by Young, are:

1. The orbits are all *nearly circular*.
2. They are nearly *in one plane* (excepting the cases of some of the little asteroids). See Fig. 200.
3. The revolution of all is *in the same direction*.
4. There is a curiously *regular progression of distances from the sun* (expressed by Bode's law, which, however, breaks down at Neptune). See foregoing table.
5. There is a rough *progression of density*, increasing both ways from Saturn, the least dense of all the planets in the system.

As regards the planets themselves, we have:

6. The *plane* of the planets' rotation, the plane of their equators, *roughly coinciding with those of the orbits* (probably excepting Uranus).
7. The *direction* of the rotation of the planets about their polar axes *the same as that of their revolution in their orbits* (excepting probably Uranus and Neptune).
8. The *plane* of orbital revolution of the satellites of each planet *coinciding nearly with that of the planet's rotation*, its equatorial plane.
9. The *direction* of the satellites' revolution in their orbits also *coinciding with that of the planet's rotation about its axis* (excepting the ninth satellite of Saturn).
10. The largest planets rotating most swiftly.

The Order Among the Stars

Significant Relations of the Stars. — The sun, as has been learned in the previous chapter, is but a star and a member of the stellar system. What are the orders of magnitude, of number, of size, of distance, of speed, of duration among these countless orbs, and how do these relations enter into the problem of the origin of the earth as one of that retinue of planets which attend upon the sun?

The stars of our system are estimated to be more than a hundred million in number. Those whose diameters are known range from somewhat below a million to upward of ten million miles and more.

Many of the stars are in reality double or multiple stars, consisting of companions so close that the two or more appear as one star to the naked eye, or even under the highest power of the telescope, the evidence of their composite nature being revealed only through the analysis of their light by the spectroscope. These double stars revolve swiftly about each other, but such internal motions must be sharply distinguished in thought from the streaming or drifting of the stars as parts of the great stellar system. Relatively to the sun they are found to move through space with speeds averaging between 10 and 30 miles per second, but ranging from less than 10 to more than 200 miles per second. They do not move, however, singly and in closed orbits, but rather in broadly scattered groups whose paths are almost straight lines. These courses of the stars must slowly curve under the aggregate attraction of the millions of stars, but can never return into themselves. The paths of groups of stars intersect other groups and are to some extent interwoven among themselves. With the passage of millions of years, the stars thus continually enter into new relations and build new configurations in the skies: a myriad host of stellar fireflies, the living and the dead, streaming through space hundreds of millions of miles per year.

Although the stars are so great in number, their distances from each other average tens of millions of millions of miles, those in our part of the stellar system averaging between sixty and eighty trillions. The star nearest to the sun, α Centauri, happens however to be at a lesser distance of about twenty-six trillions of miles.

Considering the numbers, the velocities, and the distances of the stars, what are the chances of collision between them, or of approach so close as to exercise upon each other strong tidal forces?

To bring down the dimensions of the universe to finite comprehension, we must divide the scale of nature by a thousand million. Then the earth would be represented by a pebble half an inch in diameter, circling once a year about a sun 4.5 feet in diameter, at a distance of 500 feet. The nearest star, α Centauri, would on this same scale be seen as two spheres revolving about each other at a distance apart equal to 2 miles, and each comparable in size to the sun. This double star would be situated at a distance of about 25,000 miles from our planetary system with its sun, but the other stars in this part of the stellar system would be separated from each other on the average by more than twice this distance. The Galaxy, or Milky Way, seems to be the outer zone of our stellar system, and its dimensions are only vaguely known. On this new scale it might be found to be encompassed by a circle of a hundred million miles diameter, or it might be more or less.

Chances of Close Approach. — The motion at any instant of any individual star is the result of its motion inherited from the past plus the attractions of all the matter in the universe pulling upon it in the present. If two bodies without previous motion were to be attracted toward each other, and were able to ignore the gravitative pull of all other bodies, they would move in a straight line toward each others' centers with ever-increasing velocity until collision would result. But the least inherited motion in any other direction, or the least deflecting pull upon one of them more than upon the other by other bodies would prevent to that degree a central collision, or in almost all cases any collision whatever. Now the velocities of the stars through space at great distances from each other are so great that individual stars can have almost no attractive influence upon each other. They must move in nearly straight lines past each other unless they happen to pass within a thousandth part of their average distance. It is seen then that the chances of close approach depend primarily upon the accidental crossing of their paths and only secondarily upon their mutually attracting each other. For this reason the chance of actual collisions may be regarded as absolutely negligible even considering the vast number of stars. Approach sufficiently near to generate strong tidal forces would, however, have occurred to a considerable number out of the hundred million or more of stars which are known to exist in the stellar system, but for any one individual star the chance of such approach even in a billion years would be very small. It is thought, however, that this happened once to our star, that is, to our sun of that time, in the distant past and from that disruptive tidal force was born our system of planets. Fortunate indeed has been our planetary fate, for not only did this happen so early in the sun's career that his radiant energy has been able to endure through all the ages

needed for organic evolution, but the spacing of the stars is so wide and the chance of approach so rare that no other of them has since advanced sufficiently near to throw this system into disorder, or disrupt and sweep away the earth and its sister planets as a wasted effort, and start the re-creation of a new heaven and a new earth.

The Forces of Tidal Disruption

The next question to be discussed is, Why is it that spiral nebulæ are the stellar responses to tidal forces, a fiery salute in recognition of the passing of another star?

Principles of Tidal Action. — Let M and N in Fig. 346 be two bodies passing each other in space and consider the action of the larger on the smaller. According to Newton's law the bodies attract each other directly as their masses and inversely as the

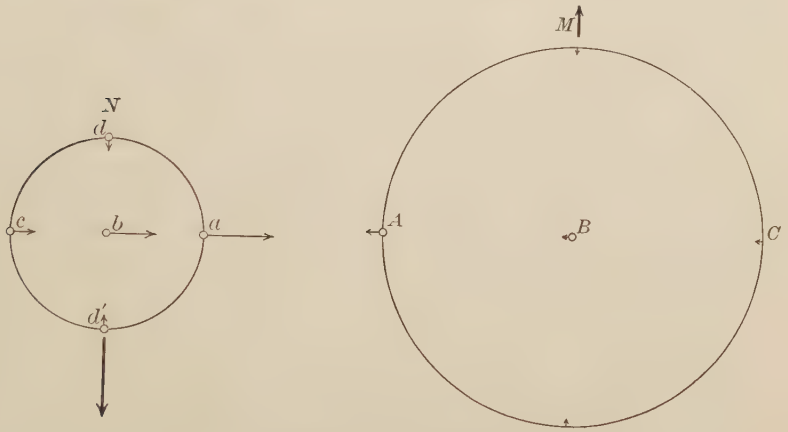


Fig. 346. — Diagram to illustrate tidal forces.

square of their distances, causing them to swing toward each other while passing by, but soon losing influence as they separate in their journeys through space. Consider three particles, a, b, c, on the line of attraction, taking them as separate parts of the smaller body. But a is nearer to M than is b, and b is nearer than c. Therefore if we represent the relative attractions by lines, these lines will correspond to the distances which the particles would move in a given time if free to obey the attraction of the other body. The line at a is longer than that at b and the latter is longer than that at c. If N was not bound together by its own gravity or rigidity, a, b, and c would therefore drift apart and fan out while passing M. Consider that rigidity is negligible, as in a

fluid globe; then, if a minus b, or b minus c are quantities which become greater than the self-gravitative force of N holding together a and c, the unity of the body becomes destroyed. The problem, however, is not quite so simple, since the influence of all other points in N must also be considered.

As the nearer part of the body is pulled from the center, and as the center is pulled from the farther side, there will, further, be two simultaneous tides of approximately equal height, but on opposite sides of the distorted body. They tend to be always on the line joining the two bodies. Thus, on the earth there are two tides on opposite sides, but the revolution of the earth on its axis, like a car wheel under two opposite brake-shoes, gives an apparent effect, to one on the surface of the earth, of a revolution of the tidal wave. As a result of the equal tides at opposite ends of a diameter there are, on any part of the ocean, two high tides in twenty-four hours.

Relations of Comets to Meteoric Streams. — In the previous chapter the meteorites were described and it was also stated that from time to time the earth in its motion around the sun passes through swarms of meteors.

Comets, compared to the earth or moon, are also small bodies. They fall or move toward the sun from outer space, swinging about it and receding again in highly elliptic or parabolic orbits. While in the vicinity of the sun, the nucleus or center develops gaseous envelopes which are driven away from it as fast as formed and constitute the familiar tails of the comets. Their lack of power to retain gases is a mark of their weak gravitative cohesion, which in turn is owing to their small mass. In passing close to the sun they would exhibit, except for their small size and the solid nature of their nucleus, the phenomena which would be shown by two passing stars. On account of these differences, however, the forces of tidal disruption work on them in another way. It has been found that a number of comets possess the same orbits as the meteoric streams (swarms of meteors), but the latter become visible to us only by the collision of their component meteors with the atmosphere of the earth. Many other meteoric streams, we infer, must therefore exist in the solar system unknown to us. The inference is strong that those comets especially which repeatedly pass too near the sun become disintegrated by tidal disruption, the action continuing upon each return until they become broken into fragments of a small size which are spread out as meteors along the cometary orbit.

Mode of Tidal Disruption in Stars. — A star is characterized by its enormous size and mass and by the possession of a gaseous constitution. The diameter and density are dependent upon the balance at every point between the tremendous expansive forces of internal heat and the equally great compressive forces due to its own gravity. If it contracts, then its surface and each component shell below comes nearer to the center, the effect of gravity upon

any shell accordingly increases inversely as the square of the new radius, and a higher internal temperature becomes necessary to balance the higher gravitative force. From this there results the paradox known as *Lane's law*, — that so long as a body maintains a gaseous constitution its temperature must rise as it contracts, even though at the same time it is radiating heat. The temperature of the interior must furthermore be higher than the temperature of the surface, because of the greater compression with depth, as is illustrated in the different strata of the terrestrial atmosphere. In those convective or slow boiling movements which are necessary in the sun and other stars in order that they should be able to maintain their surface radiation, there is then a constant liberation of energy from the depths and a system of balanced motion which if disturbed could lead in any star to an enormous explosion and blowing out of material from it.

The tide-generating force varies directly with the mass of the disturbing body and also with the radius of the body disturbed. It varies approximately inversely with the cube of the distance between the centers. The deforming force is, furthermore, greatest in the interior because the tidal forces acting on the zone at right angles to the line of force have a component which tends to squeeze in the points d, d' of Fig. 346 toward the center. The gravitative control is accordingly weakened along the line a, b, c, and is strengthened in the directions at right angles. Now apply this principle to the gaseous balanced nature of a star, and it is seen that the gaseous expansion in the line a, b, c is no longer exactly balanced by the gravitative compression, and the unbalancing is greatest in the center, where also is the region of highest compression and highest temperature. The effect is as if one squeezed a syringe bulb with orifices for exit at both ends, a bulb, however, like an air rifle, filled with gas compressed to an explosive degree.

A better analogy in some ways is supplied by the action of a geyser. As explained on page 219 of this book, increased pressure raises the boiling point of water. In a water column pressure increases with depth. Here in a natural water pipe more or less vertical, the deeper water is restrained from exploding into steam because of the pressure from the weight of the water above. But let the pressure through all the deeper parts be diminished by the upper part reaching the boiling point, turning into steam, forcing out the water from the upper part of the column, and replacing it by the substance of lower density. The whole column then becomes unbalanced, all parts flash into steam, and eruption of the geyser begins with explosive violence, the deeper water producing the most vigorous action. To revert to the exploding gaseous sphere, it is seen that, although all forces on the line a, b, c due to the attraction of M are directed toward

M, the tidal force due to a minus b and b minus c will tend to expel matter equally in both directions from the center. It is like a double geyser operating simultaneously from both ends of a diameter.

Tidal Disruption of the Ancestral Sun

Solar Prominences. — We have seen that the sun shoots out prominences to heights of nearly 300,000 miles, and at velocities ranging up to 300 miles per second. These phenomena indicate the enormous elastic and explosive energy resident in the sun's interior, an expansive potency held in restraint by the equally prodigious power of the sun's gravity.

Possible Disruption of the Sun into a Spiral Nebula. — Chamberlin states that " If, with these potent forces thus nearly balanced, the sun closely approaches another sun, or body of like magnitude . . . the gravity which restrains this enormous elastic power will be *reduced along the line of mutual attraction.* At the same time the pressure transverse to this line of relief will be increased. Such localized relief and intensified pressure must bring into action corresponding portions of the sun's elastic potency, resulting in protuberances of corresponding mass and high velocity. Dynamic considerations seem to make it clear that the sun might even thus be wholly disrupted, if the body to which it approached were much superior to it in mass and the approach were very close." Apparently a fraction of one per cent of the sun's mass would amply suffice if shot out as protuberances to make up the material necessary to form the planets and satellites of the solar system, but this may be the residue left from a far greater quantity of solar matter which took part in the tidal explosion. Thus Chamberlin conceives that a spiral nebula, having two dominant arms on opposite sides, would arise from the simple event of a close approach. It is to be expected that the arms would be knotty, that is, contain in places more condensed material or nuclei resulting from irregular pulsatory explosions of the parent body, and the knots would also probably possess rotations. In addition to the knots there would be a general scattering of the larger part of the mass in irregular nebulous clouds.

Development of the Nebula into the Solar System. — It remains to be seen how the nebula resulting from tidal disruption can become the embryo of an orderly planetary system. If the matter were shot out from great depths in the sun by its normal expansive forces plus the tidal forces, the velocity of departure might rise high above the observed velocities of 300 miles per second. If

400 miles or more it would be above the " critical velocity " of the sun. The gravitative attraction of the latter could then never reclaim that matter, because the decrease in the outward velocity due to the solar attraction would never bring the velocity down to zero and could therefore never reverse the motion of the escaping matter, and bring it back to the sun.

It is doubtful if the sun could have drawn back to itself material expelled with a velocity of even 300 miles per second, for the passing star, by lowering the gravitative power of the sun on the line passing through the two, would temporarily decrease on that line the critical velocity. In other words, it would help to drag matter away from the sun, even though that matter could not catch up to it, but would be left wandering in interstellar space, forming possibly cometary and meteoric material for other systems. But some, or possibly all, of the matter of the exploded sun may have had lesser velocities of escape and would consequently remain within its gravitative control. In so far as it was not deflected sideways by some extraneous force it would fall back on the surface of the parent as the water of a geyser falls back into its pool. But the gravitative pull of the passing star would serve as such an extraneous force, analogous to the wind which blows part of the geyser water, as it rises and falls, to one side of the basin. The matter shot out toward the passing star would be attracted sideways after it as the star receded into space. On falling back toward the sun it would consequently pass to one side and elliptical orbits of the separate particles would become established. The material shot out in the reverse direction, from the opposite side of the sun, would meet much the same conditions except that the sidewise pull of the passing star would be less on it than on the sun. It is seen that the lateral or deflecting force acting on both arms of the nebula would be due to the difference between the pull of the passing star on the arm and on the central body. The spiral arms do not then represent the path along which the material was shot out, but mark the rotation around the central body or sun, both of the axis of expulsion during the passing of the star and of the matter after it is expelled.

The spiral nebula would be developed in a plane (Fig. 340). That plane is established by the hyperbolic orbit of the passing star with the sun at the focus of the orbit. The new system would thus show in its nature features imposed by both its parents.

The correspondence in form of the innumerable spiral nebulæ hidden in the heavens but revealed by the telescope with the ex-

pectations as given by mathematical analysis is what gives strength to the conclusion that they are in fact the result of such tidal disruption as here outlined, acting upon gaseous bodies.

Origin of the Planets

Development of Planets from Spiral Nebulæ. — From such a nebulous fiery birth Moulton especially has shown how, in accordance with the laws of celestial mechanics, a planetary system could result.

The matter which has converged into the planets would be that residue of the solar tidal disruption which did not pass beyond gravitative control and did not fall back into the body of the sun. This residue is only a very small fraction of the sun's mass. It would appear probable, however, that the solar disruption was very great in order to give an axial revolution to the reaggregated matter forming the present sun, so that its equator should be, as observed, only seven degrees from the mean plane of all of the planetary orbits. The present revolution of the sun is probably due then to the whirl produced during tidal disruption and not to an axial rotation belonging to the sun before the event took place.

This brings us to the final stage in the evolution of the planets according to the planetesimal hypothesis (see Figs. 339–341). In the arms of the spiral nebula were knots or nuclei of matter constituting the cores of the planets. Four small knots, the earth-moon knot being a double one, represented the beginnings of the four small inner planets (see table, page 516). In the zone of the planetoids there was, however, no dominating nucleus, and they have therefore remained to this day largely in the planetesimal state. Four greater nuclei beyond were the beginnings of the major planets. Smaller nuclei associated with the larger marked the presence of satellites.

The orbits of the planetary nuclei and of the scattered planetesimal swarm were highly eccentric, having the form of a tangle of ellipses of all forms and sizes but lying in nearly a common plane and with a common direction of revolution about the central body. Collisions would inevitably occur at the crossing of the paths in the course of numberless revolutions and the nuclei would have sufficient mass and consequent gravitative power to retain the matter colliding with them. In this way, each planet would in the course of time clear up an orbital zone, and these zones, because of the eccentricities of the orbits of the component particles, overlapped each other with the exception of a region between Mars

and Jupiter. But Moulton has shown that in such planetary growth by accretion, an axial revolution would arise in the same direction as the orbital revolution, and that the incorporation of all the planetesimals would cause the eccentricities to cancel out, giving to the whole mass a nearly circular instead of a highly elliptical orbit. This would lead us to believe that the original nucleus was but a small part of the completed planet, so that its original ellipticity of orbit was submerged beneath the average influence of the added masses. With this growth of the planet to final form and in orderly relation to the sister planets and the parent sun, geologic history, as distinct from cosmic history, finds its beginnings.

Relations of Earth and Moon. — The moon revolves at a mean distance of 239,000 miles from the center of the earth. It has a diameter of 2160 miles, more than a quarter of the earth's diameter, but owing to a lesser density as well as a smaller volume, its mass is only one eighty-first part of the mass of the earth. Nevertheless, it is larger in relation to its primary (the earth) than any other body in the solar system, so that there is some justification for referring to the earth-moon system as a double planet.

Under the simple terms of the nebular hypothesis the moon was looked upon as made by the coalescence of an equatorial ring of gaseous matter abandoned by the earth when it had a diameter of about half a million miles. The same objections apply, however, to this hypothesis of evolution for the satellite as have been given against the hypothesis of the evolution of the planets under the terms of the nebular hypothesis.

George H. Darwin in 1879 suggested, as a result of his investigations upon the theory of tides, that the earth may have formerly revolved once in about five hours instead of twenty-four. A much greater equatorial bulge, or flattening at the poles, would then have resulted from the high centrifugal force, and this equatorial zone may have been made unstable by the rhythm of the tides produced by the sun. He conceived that one side of the earth's crust may thus have been broken away, as in a bursting flywheel which has revolved at too high a speed. The matter so liberated would begin to revolve around the earth close to it, and, gathering into a body made spherical by self-gravity, would give rise to the moon. Fisher then suggested that the bed of the Pacific Ocean basin might be the scar made by the moon's birth, and the Atlantic Ocean basin the result of that part of the continental crust which forms the Americas breaking away from the main mass represented by the Old World and drifting westward toward the depression left by the disruption. Thus Fisher would account for the formation of the ocean basins as due to the removal of a part of an outer lighter crust which went to form the moon. Darwin showed, as a part of the same problem, that, under certain conditions, the enormous tides raised by the moon in close proximity to the earth would slow down the earth's rotation like a friction brake and react upon the moon by driving it farther away from the earth. This hypothesis of the moon's origin has been widely held. It rests upon sound principles, but there are involved many uncertain factors.

Moulton has more recently reëxamined the whole problem and tested its

probability or improbability in a number of ways. He found that the moon would have had to break away from the earth when the equatorial diameter of the latter was 18,400 miles, and it appears probable that the tides raised by the newborn moon, instead of beginning to drive the moon away, would precipitate it again on the earth. If, however, the moon did get away and tidal retardation began, then the time demanded to push it to its present distance, depending upon a new estimate of tidal friction, would be hundreds or thousands of times longer than those estimates which are given by geologists for the age of the earth.

The conclusion, therefore, is that the moon never was a part of the earth's body, but that earth and moon originated as two companion nuclei in the spiral nebula and approximately at their present distance. The nucleus of the earth must have been, presumably, much more massive from the first in order to bring dominantly to it the planetesimal infall and so result in an even greater disparity of mass. The moon, thus restricted in its growth, has at its surface but one-sixth of the gravitative power of the earth. It has, therefore, never in its history been able to hold to itself either an atmosphere or an ocean. These gaseous emanations as they have been exhaled in connection with the wide-spread igneous activity of the moon have been warmed and expanded by the heat of the sun and then diffused into space. The moon shows a surface, therefore, upon which the gradational forces of air and water have never worked. Even in the expression of its internal activities it differs from the earth, deep-seated contraction with crustal wrinkling appearing always to have been absent. This contrast supports the view that the contraction of the earth is due to the enormous pressures developed by the weight of the outer parts and producing condensation of the nucleus. The fundamental distinctions in character and in history between earth and moon appear, then, to be traceable to the far greater mass of the earth at the end of its growth, and to the dominance of its nucleus even at the beginning of the formative era.

CHAPTER XXVI

PRIMORDIAL GEOLOGIC TIME

We learned in the previous chapter what were the probable cosmic stages which led up to the origin of the earth, as deduced from a study of the heavens guided by mathematical analysis. Then follows possibly the greatest blank in our knowledge.

Absence of Direct Evidence. — The history of the earth is deciphered from the study of its crust, but the oldest known rocks are lava flows and water-laid sediments belonging to the Archeozoic era. The sediments show that even at that time the orderly processes carried on by air and water under the influence of solar heat and light were in operation as in later ages. But these oldest Archeozoic rocks everywhere, so far as now known, float upon and are torn to pieces by younger igneous rocks. These, rising in molten form as granitic magmas, may have everywhere remelted and destroyed the original surface of the earth. Direct geologic study, therefore, can not recover that primordial history which preceded the Archeozoic. Neither can the direct study of the heavens help, for they show by the light of nebulæ only the stages which lead up to planetary birth, not those which follow. There is, then, an uncharted ground between the provinces of Astronomy and Geology, a *Primordial Time*, which, because terrestrial life also found its origin then, may be subdivided into an early lifeless eon, the *Azoic*, and a later one, the *Eozoic*, the eon of the dawn of life.

Dana in 1874 embraced all pre-Paleozoic time under the term Archean, which means ancient, and then divided it into Azoic and Eozoic. The Azoic, he said, "is the era in which the physical conditions were incompatible with the existence of life. But this era so far as now known, is without recognizable records." The name Eozoic was given up in 1895 for Archeozoic, which embraces the oldest known formations.

Our ideas as to the probable nature of events in that time of which we have no record are controlled by our conceptions of the nature of the preceding and succeeding eras. Our knowledge of these has increased greatly during the past generation and has accordingly profoundly modified many ideas once widely held concerning the formative stages of the earth.

Stages under the Laplacian Hypothesis

These older views were in part the direct outgrowth of the Laplacian or nebular hypothesis, in part the results of interpretations made in the early days of geologic science regarding various features in the outer structure of the earth. The stages of the earth's early history, as conceived by Dana and widely accepted until very recently, were as follows:

(1) **Astral Eon.** — The nebulous equatorial ring liberated by the primordial sun broke into parts, as described in a previous chapter, and gathered into a spheroid containing the mass of the earth and moon. As it condensed it grew hotter and for a long time shone like a star, hence the idea of an astral eon. It passed from a gaseous into a fluid globe surrounded by a heavy vaporous envelope containing the future water of the earth, or the dissociated elements thereof, and other heavy vapors or gases. It is postulated that during the early part of this eon the earth also gave rise to an equatorial ring that finally coalesced into the moon.

(2) **Azoic Eon.** — The time without life, as this eon is called, is divisible into two eras, as follows:

(*a*) *Lithic Era.* — The earlier portion of the Azoic eon is known as the lithic era, because the earth's surface was then all rock and the globe was still very hot, although there was a solid rocky crust, the *original crust*, wholly crystalline in structure, with a temperature at the beginning above 2500° F. The atmosphere still contained all of the water of the globe, all of the carbonic acid since locked up in limestone and that corresponding to the carbon now in carbonaceous and organic substances, and all of the oxygen since shut up in the rocks by oxidation, as well as that of the atmosphere and of organic tissues. As the earth shrank, due to cooling, lateral pressure and crustal disturbances were introduced.

(*b*) *Oceanic Era.* —At the beginning of this era the waters were condensed into an ocean universal over the earth, or gathered in oceanic depressions, with finally some emerging lands, the temperature at the surface of the earth being perhaps about 500° F. Tidal action now set in, and because of the friction thus engendered, the retardation of the earth's rotation began. Oceanic waves and currents and embryo rivers commenced their work about the emerged and emerging lands; the large excess of carbonic acid and oxygen in the air and water became a source of rock destruction. Before the close of the era, there arose the formation of limestones and iron carbonates by chemical methods, removing carbonic acid from the

air and so commencing its purification. Sediments accumulated for the first time without immediate metamorphism, and in these originated the earth's *super-crust.*

(3) **Eozoic Eon.** — Life now appeared in its lowest forms. This eon is also divided into eras, (*c*) *the era of first plant life,* and (*d*) *the era of first animal life.*

Objections to the Older Views

Absence of an Original Crust. — It has already been stated that the fundamental granite gneisses which underlie all other rocks contain evidence that they were upwellings in molten form and younger than some metamorphosed sedimentary rocks which they envelop. The view that these granitoid rocks constituted an original crust must then be abandoned. The gneisses which form the foundation rocks do not give any direct information as to the nature of the original crust and can at present hardly be used as a convincing argument either for or against the nebular or planetesimal modes of earth origin.

Theoretic Original Atmosphere. — The atmosphere of the Azoic eon was assumed, as we have seen, to have been very thick and dense, and it was thought that out of it was gradually condensed all of the water of the globe and most of the carbonic acid and the oxygen now locked up in the rocks. Not so long ago geologists also held that vast quantities of carbonic acid still remained in the atmosphere in Carboniferous times, and that accordingly the denser atmospheric blanket was retaining more of the sun's heat then than it has retained since that time. If this were the case, the climate of the earth should have been very warm and equable throughout its earlier history, and this belief was adhered to even after the glacial climate of the Permian was discerned; but when the much older ones of Proterozoic time were discovered, it became clearer that the climates of the geologic ages have been very much alike, that is, warm mild climates continuing for very long times, separated from one another by cooler to cold climates of short duration.

In this matter the testimony of the organic remains is equally as decisive as is the physical evidence of the glacial climates. The plants and animals of the seas and lands as far back in geologic time as the Cambrian all show in their physiological functions and adaptations that their environments were very much alike, alternating between warmer and cooler. But at the close of the eras appear times of stress and great organic destruction, along with rapid evolution, and this evidence is now seen to fall in with marked

changes in the environment, and often with glacial climates. Accordingly, there is little evidence to show that the climates since the beginning of the Proterozoic were as postulated by the older geologists in accordance with the nebular hypothesis of Laplace.

Primitive Water of the Atmosphere. — It was also held that not only was all the water on the surface of the earth suspended in the atmosphere when the earth was in the fluid state, but also all that which has since soaked deeply into the rocks. If this were true, the oceans must have been larger and there must have been more water at the surface in the earlier part of the Azoic eon than at any time since then. A study of the animal life of the present deep seas, however, gives testimony that the oceans have become deeper with time and especially since the Paleozoic era. Further, the study of volcanic emanations shows that great quantities of water are extruded by them and by the thermal springs. The older geologists said this was the percolating water returned to the surface of the earth (the old or "vadose water"), but the newer geology holds quite differently, that it is new water ("juvenile water"), freed out of the magmas deep within the earth's crust. Not only this, but the volcanoes are also liberating great quantities of carbon dioxide and constantly replenishing the atmosphere and oceans with that taken out of them and stored in the accumulating rocks.

We therefore again see that this older view fares no better with its explanation as to the origin of the earth than it does with the origin of the solar system. For these reasons astronomers, physicists, and geologists have been seeking for a better hypothesis that will explain the origin of the earth in accordance with the known facts. In this connection we need now consider but one other theory, — the planetesimal origin of the earth as propounded by Chamberlin and Moulton.

Stages under the Planetesimal Hypothesis

According to Chamberlin, there are *six stages* in the Azoic (4) and Eozoic (2) history of the earth before we come to the earliest of geologic times, all subsequent time being embraced in the seventh or "gradational stage." These stages, slightly rearranged, are defined as follows:

(1) **Nuclear Stage.** — The earth started in a spiral nebula, with the nebular knot acting as a nucleus, and increased by gradual condensation as planetesimals were gathered into it, until it became a small planet which continued to grow by the capture of more planetesimals. The diameter may have been between 2000 and

3000 miles. At first the discrete matter of the nucleus was held together by mutual gravity, and later the whole passed gradually into a solid mass.

(2) **Initial Volcanic Stage.** — Before the earth grew to any large part of its present mass, the self-compression which arose from its own gravity, when at a diameter of about 2000 to 3000 miles, is thought to have produced sufficient internal heat to have reached the melting points of the common kinds of rock under low pressures, and as this heat crept outward, it would reach rocks at pressures that would permit liquefaction. Moreover, as has been said above, as soon as volcanic action was established it is believed to have made notable contributions of gas to the atmosphere.

The internal heat may in part have been produced by the infall of planetesimals, and an unknown amount was probably inherited from the nebular knot that constituted the original earth-nucleus. The chief source of internal heat is, however, assigned to the progressive interior condensation of the growing body as planetesimals were added to its surface. Another source of heat lay in the atomic and molecular rearrangement of the growing nucleus. The highest temperature must have been at the center, diminishing toward the surface.

(3) **Initial Atmospheric Stage.** — There may have been a stage after the nucleus was condensed during which the earth was too small in mass and consequently too weak in gravitative power to hold to its surface the gases of an atmosphere, but if the earth then had a mass at least one tenth of that which it has at present, it probably had a limited atmosphere like that of Mars, gravity then overcoming the tendency of the gas to diffuse into space. If it was much smaller than this, it probably had little or no atmosphere. The moon has none because of its small mass, which is but one eighty-first of that of the earth. As the earth grew larger, atmospheric molecules were gathered to it, and sooner or later it gained the power to hold them, and accumulated an atmosphere. Later on, as volcanic action set in, the occluded and condensed gases of the rock material were given out and were added to the atmosphere. These gases of the interior nucleus were hydrogen, carbon dioxide, and carbon monoxide in leading amounts, and marsh-gas and nitrogen in small quantities; in the atmosphere they occur chiefly as water-vapor, carbon dioxide, and nitrogen. With such an atmosphere also goes the possibility of standing bodies of water, and in this atmosphere and hydrosphere lie the necessary materials and environment for the origination of life in its lowest forms.

Just what the temperature may then have been is unknown, and it is possible that it was not yet favorable for life. It may have been that life began at this early time; if not, it certainly became possible long before the earth attained its full growth through accretion.

(4) **Initial Hydrospheric Stage.** — Water in the form of gas is light and active, and may at first have escaped; but when the earth had attained sufficient size, water vapor was held in the atmosphere, and when, at length, the point of saturation was reached, it took the liquid form and initiated the hydrosphere, which, however, had its inception in the third stage. We have seen that the source of the water, according to the hypothesis, was the same as that of the atmospheric gases.

According to Chamberlin, it is probable that as the planetesimals were gathering upon the small earth they did so irregularly geographically, thus producing an uneven surface. Accordingly, when the water accumulated upon this surface, it gathered in these accidental depressions, making innumerable small bodies of fresh water. These bodies of water initiated *the origin of the oceans.* The planetesimal material which afterwards fell into these lakes was protected from weathering, while the material that fell on the protuberant areas was exposed to weathering and leaching, leaving behind siliceous residues, with an attendant lessening of specific gravity. Thus the depressed areas tended toward potentially higher specific gravities, and hence toward still further depression when deforming stresses were brought to bear on them, while the elevated areas tended to grow relatively lighter and more protuberant under the stress of deformative movements. Therefore, the differentiation of the oceanic basins from the continental protuberances began almost as soon as the hydrosphere started to gather, which was long before the earth had reached its present size, and has continued to the present time.

This evolution is of fundamental geologic importance, for it involves the origin of the ocean basins and of the continental platforms, and these constitute at once the grand topographic features of the globe, the great units of deformation, and the controlling physical factors in the evolution of life. It is assumed that this evolution began when the earth had attained the size of Mars, which has a diameter of about 4200 miles, for it then began to be able to retain water vapor in its atmosphere and consequently oceans upon its surface. The subsequent growth of the earth, therefore, formed a shell about 1900 miles thick, and it is within this shell that the physical evolution of the oceans and continents has taken place.

Modified Theories of the Hydrospheric Stage, by Professor Barrell

This series of events, as outlined by Chamberlin, is a logical outgrowth of the planetesimal hypothesis, but that hypothesis is, of course, sufficiently elastic to accommodate itself to many possible modifications. This view of the origin of continents and ocean basins, for example, depends upon a sub-hypothesis of differential weathering proceeding effectively and dominating the surface processes from that stage when the growing earth could, by virtue of its increasing gravitative power, first begin to hold water to its surface in liquid and gaseous form. We may, however, consider the contrary postulates that erosion and weathering may not have been effective in this way or that planetesimal infall proceeded so much faster than weathering and erosion as to make the latter processes wholly subordinate in determining the nature of the outer shells. Under such a postulate, the origin of continents and of ocean basins would have to be sought in other causes. There is some evidence which suggests that this alternative sub-hypothesis may be nearer the truth than the one whose consequences have been described in detail.

Three Hypotheses as to the Nature of the Earth's Interior. — As to the nature of the earth's deep interior but little is positively proved. That little may be summed up in the statement that it is very dense and very rigid. Beyond this, our conclusions must be guided by probabilities as suggested by hypotheses which are in accord with known natural phenomena and known natural laws. As to the chemical composition of the earth's body, three views which have been entertained are worthy of mention.

(1) *Interior of Metallic Iron.* — First, it has been thought probable by many that the core of the earth for some 6000 miles in diameter is of metallic iron. This in turn is surrounded by a rock envelope which in the deeper parts is thought to be very basic, that is, high in content of basic elements represented by iron or other metals, low in the acidic element, silicon. Such rocks are the dark and heavy basalts and gabbros. Toward the surface it is thought, according to this view, that the lighter and more siliceous rocks prevail, marked by the presence of quartz. The typical example of such rocks is granite. It is thus assumed that the increase in density in the earth is essentially due to progressive changes in chemical composition. The usual explanation of the origin of such a stratification of elements is to assume that the earth was once thinly molten throughout, during which stage a liquation took place analogous to the separation of the slag upon the surface of the molten iron in the reservoir of the blast furnace. There is really no evidence of such an arrangement, and it is difficult to see how, under it, the earth could later solidify throughout. This view is largely an inheritance from the Laplacian hypothesis, and, furthermore, neglects as unimportant the condensing effect of pressure.

It is known that pressure increases with depth to a maximum of about 45,000,000 pounds per square inch at the earth's center. Such pressures are vastly beyond the reach of laboratory experiments, so that their effects in compressing rocks are not known. Matter becomes more incompressible as it is condensed and probably reaches an ultimate limit. This and the central heat are, in fact, all which prevent the rocks from being squeezed into a minute fraction of their volume as seen at the surface of the earth. It is possible, though perhaps not probable, that rocks may be compressed at the center to a third or perhaps a quarter of the volume which they possess when free from pressure. The planetesimal hypothesis suggests as most probable that the earth throughout is of the

nature of igneous rocks but has been solid and rigid from the time of its origin, save for the generation of magmas. The distribution of densities so far as known is in better harmony with this view of the earth's interior than with the view which neglects the great influence of compression and assumes the existence of a central iron sphere. On the other hand, there are some indications given by experiments at very high pressures, that the more rigid bodies, like rock and metals, may not be compressible to one half of their ordinary bulk. The evidence has been interpreted, however, in opposite ways by different physicists, and a positive conclusion has not yet been reached. The composition of the earth's central portions is, therefore, an open question.

(2) *Interior more nearly like Basalt.* — But if the earth consists of silicate rocks throughout, are these basic, intermediate, or acidic in composition?

The study of igneous rocks has led many to believe that at the initiation of a period of vulcanism the great reservoirs of magma have a basic or intermediate composition. The granites are a later differentiation product, separating like cream from milk, and rising, by virtue of their lesser density, to the higher parts of the reservoirs. This brings us to the second view of the chemical nature of the earth's interior — that the average composition probably approaches throughout to that of basalt rather than to that of metallic iron on the one hand, or granite on the other.

We are prepared now to consider the supposition of the influence of weathering upon such an earth during the outer 1000 or 2000 miles of its growth. It is not clear that it would result in such a lateral segregation of densities as to build, on the one hand, denser and therefore depressed oceanic crustal segments, and, on the other, lighter and therefore elevated continental areas.

In the first place, free oxygen could hardly exist in the atmosphere in contact with such wide-spread basic rocks as more than a trace, since the large amount of ferrous iron and sulphur of these rocks would rapidly consume such oxygen as existed. In the second place, there would be little or no quartz to make sand residues as a result of weathering and erosion, and the great amount of ferric oxide going with the clay would prevent this from being a lighter part of the weathered products. There are other difficulties in accounting for the origin of ocean basins and continental platforms in this way, but they are also involved in the third view, which may now be considered.

(3) *Interior more nearly like Granite.* — Assume, as a possible alternative supposition, that the average composition of the infalling planetesimals was of the nature of granite, or that igneous activity during the later growth stages of the earth kept separating granites as surface rocks. Then chemical weathering would tend to separate the insoluble siliceous portions, chiefly quartz and clay, from the metallic portions, the metals forming soluble bicarbonates, sulphates, and chlorides. This would have resulted in a rapid saturation of the gathering ocean waters by the very soluble salts of sodium and potassium. The excess of these salts would thenceforward have to be deposited, and the ocean would continue to exist in a saturated state. But the present oceans are very far from being saturated. The waters of the Dead Sea, for instance, hold from 20 to 25 per cent of salts, whereas the ocean water holds but 3.3 to 3.7 per cent. This oceanic content corresponds to the weathering and erosion of a layer of igneous rock only about half a mile thick if spread over the globe, or less than 2 miles if derived from the continental areas. The lack of more salt in the sea can not be ascribed to the elimination, in the form of salt, of deposits from waters of the present salinity, for all those known comprise but an insignificant fraction of the salt which is in

solution, and the processes of abstraction are inadequate to account for such a hypothetical early precipitation. If the ocean had once been saturated, there is no means known by which its salinity could be so decreased save by dilution with fresh juvenile water from the depths of the earth. This would force us to believe, therefore, either that planetesimal infall until its latest stages was so rapid as to render negligible the influence of weathering, or that the greater part, probably eight or nine tenths, of the ocean water was liberated by the igneous activity of the Archeozoic and later eras. The first of these two suppositions seems more probable, but both may in a measure be true.

It is, moreover, not clear, even if weathering of granitic rocks did go on accompanying planetesimal infall, that any such distinction in relief would arise as now separates continents and oceans. The calcium, iron, and magnesium carbonates are heavier, it is true, but the alkaline chlorides are lighter than the siliceous sands. The soluble salts, furthermore, show tendencies to be precipitated in shallow waters rather than on the bottoms of ocean basins.

As another suggestive line of evidence, igneous activity brings up samples of earth substance from a great depth, and those erupted in oceanic islands show a higher average specific gravity than those erupted from volcanoes on the continents. But the differences in composition show that soda and potash tend to segregate with silica. This is not the kind of separation which would go forward as a result of *weathering;* rather is it the kind of difference which is found to arise by a liquation or separation of molten magmas into lighter and heavier portions analogous to the liquation of an emulsion of oil and water.

It seems probable, furthermore, that considerable tracts of continental lands have, in the course of later geologic time, broken down and added their areas to the ocean basins. The development of the latter can, then, not be wholly ascribed to causes operating only during the earth's formative eon. Changes in density, effected possibly by broad igneous activity, may be a more important cause, resulting in progressive subsidence of the heavier sections of the crust.

Conclusions as to the Nature of Earth Growth. — The best conclusion with present knowledge seems, therefore, to be that planetesimal infall dominated the activities on the earth's surface until its complete growth had been nearly attained. This may be due to a relatively great rapidity of infall, or to weakness of erosion and sedimentation in that formative eon, owing to a thin primal atmosphere, a meager ocean, or an ineffective warming of the earth's exterior.

(5) **Initial Life Stage of Eozoic Time.** — Suitable conditions for life did not exist until after some notable development of the atmosphere and the hydrosphere, but, as these were gathered about the earth at an early stage, it is possible that some forms of life began long before the earth was full-grown. The necessary conditions for life may have obtained when the earth nucleus was the size of Mars. Under the planetesimal hypothesis, therefore, the time during which life may have existed on the earth is very much longer than that assumed under the older hypotheses.

Hypotheses as to the Origin of Life upon the Earth, by Professor Barrell

H. E. Richter in 1865 advanced the speculation that living germs might be eternal, pervading all space. This is the hypothesis of "cosmic pangenesis."

Arrhenius (1908) raised the speculation of cosmic pangenesis to the dignity of an hypothesis, holding that the pressure of light was able to drive germs from the outer atmospheres of planets, distributing them through the depths of interstellar space. He holds that the absence of an atmosphere and the cold of space would indefinitely suspend the life of germs without destroying their vitality. The spores or germs would be swept outward with increasing velocity until, on wandering into the neighborhood of other stars, the light pressure of the latter would tend to arrest their meteoric speed and eventually turn them away on another interstellar journey. While in the state of arrested flight, however, they could be attracted to or come into contact with planets of the visited system. Most of the germs would be burned like meteors by frictional impact at high speed against the planet's atmosphere. In those cases, however, where the germ overtakes or is overtaken by the planet it might enter the atmosphere at low velocity and thus be enabled to seed the planet with life.

This hypothesis does not pretend to solve the ultimate origin of life, but only the origin of life upon the earth. It puts off the ultimate origin of living protoplasm as another problem, perhaps insoluble. Under its terms it is to be expected that any planet may develop life whenever its surface conditions offer the necessary environment of atmosphere and warmth.

Chamberlin, however, considers it highly improbable that the vast and empty interstellar spaces should be sufficiently seeded with spores to afford that rare chance of a germ encountering and successfully entering the atmosphere of a planet in another system without having its vitality destroyed, and it must further be remembered that even the possibility of the escape of spores from a planetary atmosphere can not in the nature of things be regarded as demonstrated. Chamberlin considers it more probable that life originated on the earth independently of other planetary bodies. Organic chemistry has not yet shown how living protoplasm could be organized without the presence of antecedent living protoplasm, but Chamberlin thinks that the necessary conditions may have arisen during the infall of planetesimals and after the development of the primitive atmosphere and ocean. The porous crust would have offered a great variety of chemical and physical conditions. Gas-laden, permeating waters in the presence of warmth and in a porous medium may have built up here and there colloidal substances capable, by catalytic action, of carrying forward the construction of complex molecules from carbon with other elements. The earth being as yet sterile, this primordial protoplasm would not have become attacked by carnivorous germs and would thus have had opportunity to evolve into that efficient chemical and physical form wherein it could continue its own existence.

It is seen from these sketches of possible modes that all hypotheses regarding the origin of terrestrial life are, in the present state of knowledge, highly speculative. Until there is accumulated a larger basis of significant data, the problem can hardly be regarded as within the domain of science.

Under either view which has been given, it seems that life may have arisen on the earth long before the latter had attained its full growth and present diameter. With the introduction of plants and animals there came into action through their physiological activities all of the great factors potential in the earth's physical evolution, ready to dominate the geologic activities of the surface as soon as the formative era was ended.

(6) **Last Stage of Planetesimal Accretion.** — During all the previous stages the earth was growing larger through the gathering in of the planetesimals. It is probable that the accretion was rapid at first, causing the diameter of the earth to increase more rapidly. Finally, the time came when practically all of the planetesimals of the original nebula under the influence of the attraction of the earth and the moon had been gathered. The earth probably had a greater equatorial diameter then than now (7918 miles), but how much shrinkage has taken place since is not yet known.

Some internal heat may have been retained by the nebular knot or nucleus, and it is thought that this initial heat increased with the growth of the mass. The maximum of heat may have been attained after the earth had arrived at bodily maturity, due to the increased compression of increased mass, supplemented by heat of chemical and radio-active origin. With the increase of internal heat came the rise of volcanic activity, and it has continued intermittently ever since. During long times the rising of this heat may not have been very active, but periodically it became great, and these periods of marked vulcanicity seem to fall in with the times when the earth is undergoing either regional (orogenic) or general (epeirogenic) mass movements, due to shrinkage that is brought about by internal condensation, not so much by loss of heat as by increase of density due to atomic or molecular internal alterations in response to the pressures generated by gravity.

What this internal heat was then or is now no one knows. However, it has been stated in the first part of this book that a temperature of at least 2000° C. (3600° F.) may be reasonably assumed to exist in the region of the source of some of the volcanic lavas.

(7) **Gradational Stage.** — After the growth of the earth had ceased, the surface was no longer subject to continual burial, but was exposed ever afterward to the action of air and water, and heat and cold. The material removed by these agents from the higher parts was deposited at lower levels and in the main in the oceanic basins and their continental overlaps. The seventh stage, therefore, embraces all subsequent geologic time, and its dominant process was gradational. Vulcanism and diastrophism were other active geologic processes, of slight import throughout long ages, but of marked character during the short intervals which divide geologic history into the periods and eras of time.

CHAPTER XXVII

THE ARCHEOZOIC ERA

History of Classifications

The greater part of Canada, or, rather, the Canadian Shield, of over 2,000,000 square miles in extent, exposes the oldest portion of the North American continent (see Figs. 348 and 365). Here lies the very complex record of event upon event, made during the earlier eons of geologic time.

Fig. 347. — Sir William Logan (1798–1875). Father of Canadian geology and author of Laurentian and Huronian.

Work of Sir William Logan. — The beginning of the unraveling of this history fell to William Edmond Logan (1798–1875), the first director of the Geological Survey of Canada. He did his work well, and, as he inaugurated the detailed study of pre-Cambrian formations, he has been called the Father of Pre-Cambrian Geology.

Geikie says of Sir William Logan: "At the very beginning of his connection with the Geological Survey of Canada in 1843, Logan confirmed the observation [of previous geologists] that the oldest fossiliferous formations of North America lie unconformably on a vast series of gneisses and other crystalline rocks, to which he continued at first to apply the old term Primary. By degrees, as he saw more evidence of parallel structures in these masses, he thought that they were probably altered sediments, and he referred to them as Metamorphic." After years of labor on the part of himself and his associates, "he proposed for these most ancient mineral

masses the general appellation of Laurentian, from their development among the Laurentide mountains. . . . In the course of his progress, he came upon a series of hard slates and conglomerates, containing pebbles and boulders of the gneiss, and evidently of more recent origin, yet nowhere, so far as he could see, separable by an undoubted unconformability. These rocks, being extensively displayed along the northern shores of Lake Huron, he named Huronian. He afterwards described a second series of copper-bearing rocks lying unconformably on the Huronian rocks of Lake Superior. He thus recognized the existence of at least three vast systems older than the oldest fossiliferous formations. . . .

"Subsequent investigation has shown the structure of the regions which he explored to be even more complicated and difficult than he believed it to be. . . . But he will ever stand forward as one of the pioneers of geology, who in the face of incredible difficulties, first opened the way toward a comprehension of the oldest rocks of the crust of the earth."

Work of the International Committee of 1905. — In 1905 a committee of geologists was appointed by the governments of Canada and the United States to agree upon a sequence of formations and a nomenclature for the pre-Cambrian rocks of the Lake Superior region, the best known area of these ancient formations in North America. The report of this International Committee was a great advance upon the older classifications still seen in text-books, and it may have seemed to some at that time to have fixed the larger divisions, leaving for future work only the development of details. However, our knowledge of these rocks has since grown with leaps and bounds, and the question of another revision was taken up by the Twelfth International Geological Congress in the summer of 1913. At least four somewhat different classifications were there offered, and while the table presented in Chapter XX follows in the main the one of Coleman, yet the views of Leith, Adams, Lawson, Collins, Miller, and Knight have also been considered. It is, however, a foregone conclusion that this classification, like those preceding it, is by no means final.

Method of Correlation. — In deciphering the pre-Cambrian chronology the geologist has no fossils to depend upon, and the criteria used in the working out of the geologic sequence are: (1) similarity of rock character, (2) structural nature of the rocks, (3) superposition of the formations, (4) crustal movements, and (5) cycles of erosion. In order that these various phenomena may be fully evaluated in a time table, it has become necessary to in-

clude in the table the periods of deformation and the times of wide-spread erosion, and to give names to them as well. The incorporation of these principles is a feature of the pre-Cambrian table presented on pages 444 and 445, which in the main follows the scheme offered by Barrell in 1914. Periods of igneous invasion and crustal revolution are shown on the right, and periods of sedimentary record on the left. The shorter erosion intervals indicating the breaks which separate periods are shown by narrow spaces, while the great named intervals are brought out by wide spaces. Even this magnification, Barrell thinks, minimizes the long duration of the great erosion intervals. The result, however, serves to make prominent the two most significant and distinctive features of the pre-Cambrian: (1) the wide-spread crustal revolutions, characterized by vast upwellings of molten rocks; and (2) the profound depth to which erosion has planed, revealing over great areas the former levels of the crust which, while deeply buried, were subjected to regional metamorphism — levels whose original place was miles beneath the present surface.

Length of Pre-Cambrian Time. — It is generally admitted by geologists that the time back of the Cambrian, the first period with an abundance of fossils, was extremely long. Coleman says of it: "At present no part of the earth's history is attracting more attention than the pre-Cambrian, and we are gradually disentangling obscure relationships and opening out a wonderful vista into the past which has already doubled the length of geological time, and bids fair to make the post-Cambrian record only an appendage to the far more important pre-Cambrian story of the world."

Terminology. — In regard to the use of the names *Archeozoic* and *Proterozoic*, for the Age of Unicellular Life, and the Age of Primitive Marine Invertebrates, respectively, the following should be stated. As the post-Proterozoic eras are marked by an abundance of life preserved as fossils, it is highly desirable to bring out this fact in the names through the ending *zoic*, which means life. In the pre-Cambrian eras, however, fossils are exceedingly scarce and a classification of the formations on this basis cannot be developed, yet it is established that life existed throughout the Proterozoic and in all probability the Archeozoic as well. Therefore, the usage of *zoic* in these names is also desirable and harmonizes them with those used for the later ages, even though the classification of the rocks in the older eras is by geologic structure rather than by fossils. Because no direct and accepted evidence of life has been found in

the Archeozoic era some geologists prefer to call it *Archean* (means very old), a non-committal term once applied to all pre-Cambrian formations. *Azoic* (without life) and *Eozoic* (dawn life) are other terms which have been used, but in this book Archeozoic is preferred because it means oldest or primal life, a significance in harmony with our present conception.

Divisions of Archeozoic Time. — In Chapter XX, the geologic events of Archeozoic time are given in tabular form and in relation to the younger formations; below, only the more important events are listed, arranged from younger above to older below:

Table of Archeozoic Events

Erosion record	Ep-Archeozoic interval of profound erosion	
Diastrophic record	Laurentian Revolution, mountain building, and first intrusion of Laurentian granites	
Formation record	Keewatin series	
	Coutchiching formation	Grenville series of calcareous sediments, mainly younger than Keewatin
	Unrecoverable beginning of earth history	
	Cosmic history	

Record of Archeozoic Formations

In Chapter XXVI were described the events that are thought to have taken place during Cosmic time, and, as the earliest geologic conditions preceding the Archeozoic era are unknown, we will proceed to a presentation of the oldest formations known to geologists. For the distribution of the Archeozoic formations see map, Fig. 348.

Basement Complex. — The most ancient rocks at the surface of the earth are often referred to as the "Basement Complex," because they are at the base of the known geologic sequence, and because their internal nature and structural characters are usually so altered and complex that their unraveling has given rise to great perplexity among geologists.

General Characters. — The formations so far determined in the Lake Superior country are the Coutchiching and Keewatin, and farther east the Grenville series of sedimentaries and volcanics; all of these have usually been so repeatedly invaded by intrusions of the dominant Laurentian pink granites that they have been altered completely and their original characters greatly obscured (see Fig. 352). So prevalent are the Laurentian granitic rocks that they cover more than 90 per cent of the Lake Superior country, and for a long time, therefore, they were regarded as the original

Fig. 348. — The surface distribution, in black, of the undifferentiated Archeozoic and Proterozoic formations. B. Willis, U. S. Geol. Surv. Also see the Geological Map of North America at the end of this book.

cooled surface, or crust of the earth, upon which the above-mentioned formations rested. During the last decade, however, it has become clear that these granites are not older than the formations they seem to underlie, but that they are really younger, for they have upwelled from unknown depths of the earth, have broken up the older rocks, and shattered and invaded the formations above them. In this invasion and injection of the older rocks they have absorbed the material of the latter into themselves and forced their own emanations into the rocks enveloping them. Geologists, therefore, do not as yet know upon what foundation these older invaded formations lie, and it has been said that they "rest upon nothing." Although, from the standpoint of their origin, they do rest upon nothing known, in actual superposition they rest or float upon the younger Laurentian granites. Hence it should not be forgotten by the student that these basement granites are intrusives and younger in their genesis than the Coutchiching, Keewatin, and Grenville series, which rest upon them.

The Archeozoic formations have been described by Van Hise and Leith as a crystalline "complex of basic and acidic [that is, ferromagnesian and feldspathic] surface and deep-seated igneous rocks, of schists and gneisses in part derived from them and in part of unknown origin, and of shreds and small masses of metamorphosed sediments, all unconformably below and older" than the Proterozoic sedimentary rocks. "The sedimentary rocks include slate, graywacke, conglomerate, tuffs, iron formation and marble." The Archeozoic, as a whole, is homogeneous in its heterogeneity, that is, it is alike in its extraordinary complexity. "Its characteristic, though not universal, structure is cleavage or schistosity, often much folded and contorted. It frequently possesses also a banded structure, sometimes developed with the cleavage during rock flowage and sometimes due to minute parallel igneous intrusions parallel to the schistose layers." See Figs. 256 and 259.

The rocks of the Archeozoic include "(1) dominantly plutonic and surface igneous rocks, (2) [usually] small masses of sediments, (3) considerable masses of schists and gneisses clearly derived from secondary alteration of the igneous and sedimentary rocks, (4) very subordinate amounts of gneisses resulting from subcrustal fusion of sediments, and (5) other schists and gneisses of unknown origin."

Geographic Distribution. — Archeozoic formations are known in many countries, but chiefly in North America, Finland, Norway, Sweden, China, and Australia. In North America the greatest

Fig. 349. — Eastward view up the Kaibab, Grand Canyon of the Colorado, Arizona. The horizontal Paleozoic strata (4300 feet thick) rest upon the contorted and peneplained Archeozoic. U. S. Geol. Surv. *V*, Archeozoic (Vishnu schist); *U*, thinned edge of Proterozoic (Unkar); *T*, *BA*, *M*, Cambrian (Tonto); *R*, *Ss*, *Ssh*, *C*, Mississippian and Pennsylvanian.

area is that of the Canadian Shield, with much smaller areas in the Adirondacks of New York and in the highlands of New Jersey and southeastern New York. Similarly metamorphosed rocks, perhaps of the same era, occur in the southern Appalachians. Other exposures are found in the Grand Canyon of the Colorado (Fig. 349) and in the Rocky Mountains (Fig. 348). However, throughout the Cordillera there occur indiscriminately great areas of granite bathyliths, and, while most of these are Mesozoic and Cenozoic intrusions, Lindgren estimates that about 10 per cent of the region is occupied by bathyliths of Archeozoic time, nearly 80 per cent of which consist of granite.

Graphite. — The attention of geologists has long been attracted to the great quantity of graphite in the Archeozoic strata, chiefly in the quartzite-schists. Sir William Dawson long ago said there was more graphite disseminated in the Grenville series than there is carbonaceous matter in the entire Carboniferous (coal-bearing) system. Bastin states that in the Adirondacks the graphite varies from 3 to 10 per cent by weight of the rock. Near Hague, on Lake George, New York, occur alternating layers of graphitic schists from 3 to 13 feet thick, and the appearance is that of a fossil coal-bed. This graphite is believed to have been derived in the main from carbonaceous or bituminous shales, of organic origin, and probably the residuum of primitive marine plants.

The **Coutchiching formation** is the oldest series of sedimentaries known and occurs typically in the Rainy Lake country of Canada north of Minnesota. Its thickness at the very least is 4600 feet, and it originally consisted mainly of carbonaceous shales, now metamorphosed into mica schists and dolomite, both probably of marine origin.

The **Keewatin series** overlies the Coutchiching and consists almost wholly of the most ancient lava flows, basalts, and ash rocks. The lavas flowed in the main over the sea bottom, as is shown by their pillow structures. All of these igneous rocks are now altered into greenstones and green schists. The sedimentary strata are less prevalent and consist of ordinary slates, black slates rich in carbon, and iron-bearing formations, with little of dolomites and limestones. Their combined thickness varies between 6500 and 23,700 feet, of which the greater amount is of igneous origin.

Characteristic of the Upper Keewatin are the banded jasper and iron-ore formations that locally attain to 1500 feet in thickness. The hematite and magnetite ores are interbedded with zones of silica and limestone and all are often underlain by carbonaceous slate, a fact of significance in the genesis of the iron ores, since it suggests the agency of life in their formation, as discussed previously, page 170.

Grenville Series. — In the Province of Ontario north of Lake Ontario and east of Lake Huron occurs a vast succession of essentially calcareous strata. We were first made acquainted with the series by Logan, who gave the rocks their name

from Grenville township, although they are known to cover an area of 83,000 square miles. More recently Adams and Barlow have studied the series in detail and have deciphered its relations to the surrounding granites, confirming the intrusive origin of the latter as announced by Coste in 1886. In a single section these geologists determined the thickness as over 94,000 feet (nearly 18 miles), and more than one-half of it is calcareous. Originally this magnesian limestone and dolomite was fine-grained and blue in color, but it is now altered into a pinkish, coarsely crystalline marble. These marbles occur in thick bands, and with them are associated quartzites that have been changed from sandy sediments. There are also interbedded thick bands of hornblende-schist and rusty-weathering gneiss, the former resulting in part from the igneous invasions, in part from alterations of the calcareous rocks by the molten magmas, while the gneiss is the metamorphosed product of what were originally clay shales. This is not only the thickest series of Archeozoic rocks, but also the greatest single succession of limestones known.

The Grenville limestones have been repeatedly invaded by the Laurentian granites, which have not only metamorphosed them into marbles but have also either burned out their carbon or converted it into graphite, while the remaining iron oxide has given the marble its pink color. Serpentine is also often present and in places affords a distinctly banded concretion-like material, often regarded as the earliest known fossil or *Eozoön*, described on a later page.

Lavas of the Grenville Series. — Miller and Knight have found a succession of lavas at the base of the Grenville series. They correlate these lavas with the Keewatin of the Lake Superior region, and place the Grenville as younger than the Keewatin but older than the Paleolaurentian invasion of granites. It may be questioned, however, if these basal lavas are surely Keewatin. Similar volcanic series recurred more than once in pre-Cambrian time, and in the Lake Superior region the Keewatin is the oldest formation resting on the granites. Bathylithic invasions of granites are normally preceded in an earlier stage of the same cycle of igneous activity by outpourings of basaltic lavas and breccias. The Keewatin lavas and Paleolaurentian granites of Lake Superior may, therefore, be genetically connected, but the granites — regarded as Paleolaurentian — invading the Grenville sediments are so far separated in time from the basic volcanics underlying the vast thickness of the Grenville that these two groups of igneous rocks cannot be genetically related. This, then, makes strong the necessity of reasonably proving the Keewatin age of the pre-Grenville volcanics before the Keewatin or post-Keewatin age of the Grenville can be regarded as established. The problem is seen to be one of the first importance, since it deals with the opening of the knowable geologic history of the North American continent. (Barrell.)

Evidence of Life in the Archeozoic

There is no *direct* evidence of a positive nature as yet to show that fossils occur in strata of Archeozoic time. Long ago, however, Sir William Dawson described from the Grenville limestones *Eozoön canadense*, which means "dawn animal of Canada." For a time many accepted these globular masses, sometimes several feet in diameter, as of organic origin and they have figured in many text-books as such since 1864, though no one successfully showed to

what class of animals they belonged. They certainly are not Protozoa as assumed by Dawson. These masses consist of irregularly alternating thin calcite bands and dark green layers, usually of serpentine, and result from metamorphism of the limestone. They are now regarded as probably of organic origin and are thought to be calcareous depositions made by marine plants (algæ).

The *indirect* evidences of life are found, on the one hand, in the presence of carbon in the sediments in the form of graphite, and on the other, in the oxidation to hematite or magnetite of iron oxide which was originally present in the sediments in the forms of ferrous carbonate or ferrous silicate. At the surface of the earth carbon exists in the form of carbon dioxide, either free in the atmosphere or combined with the metallic oxides as carbonates. Under these surface conditions carbon becomes separated from oxygen so far as known only through the agency of living protoplasm and sunlight. In plant tissues in the presence of the leaf green (chlorophyl), the living protoplasm is able by the energy of light rays to chemically decompose the carbon dioxide absorbed from the atmosphere. The carbon is then built up into starch, the oxygen is exhaled. In so far as complete decay ensues upon the death of the tissues, the carbon recombines with oxygen into carbon dioxide and the organic cycle is completed. To the extent, however, that the organic matter is removed from contact with the air, oxidizing decay is prevented. Distillative destruction sets in instead — the first stages by bacterial action — and a residue of elemental carbon remains in the sediments (see also discussion under peat, page 164). The presence of graphite in Archeozoic sediments is therefore an indirect proof of considerable strength that not only did a lowly plant life swarm on the earth in this earliest known era, but that the rays of the sun also reached the surface. There was at that time no impenetrable cloud mantle darkening a primordial atmosphere.

It has long been held, but on insufficient grounds, that the mere presence of limestone and iron-ore constitutes also indirect evidence of life. This, however, is a conclusion not soundly based. The precipitation of limestone would go on in shallow, wave-agitated waters even without the presence of life, provided that an atmosphere containing carbon dioxide reacted through the agency of rain upon a land of igneous rocks. It seems entirely probable that denitrifying bacteria lived then as now and took advantage of the presence of the calcareous salts, but it is seen that this must be proved by detailed studies of the limestones and cannot be assumed as a cause of their existence. As to the mode of formation of the pre-Cambrian iron-ores, Van Hise and Leith have definitely expressed the reasons for believing them chemical precipitates due to ferrous salts in ocean waters reacting with solutions of alkaline silicates (Monograph 52, U. S. Geol. Survey, Chapter XVII, 1911). The subsequent partial oxidation of these ores to the ferric form, however, implies the presence of free oxygen, and this is an indirect suggestion of the existence of plant life, though not so strong as the existence of graphite in sediments. The mere presence of limestone and iron-ore cannot, therefore, be used as evidence of life in the Archeozoic. (Barrell.)

Conclusions Regarding the Archeozoic

Absence of Oldest Archeozoic Rocks. — Geologists have as yet no evidence as to what took place in earliest Archeozoic time,

nor have they seen the original foundation upon which the Coutchiching, Keewatin, and Grenville series rest. The evidence, therefore, is positive that the former foundation of the Canadian Shield, that is, the rocks older than those now resting upon the Laurentian granites, has been displaced or re-fused by the great upwellings of these, the most ancient of known igneous rocks. With Coleman we therefore agree that if the earth ever passed through a period of great heat, it was at a time too remote in the past to leave a geological record. Or, in the language of Adams and Barlow, "the probability of finding at any accessible portion of the earth's surface the original basement on which sedimentation was inaugurated is somewhat remote."

Known Archeozoic Rocks. — From Labrador to Lake Superior, through a distance of more than 1400 miles, there extends along the southern side of the Canadian Shield the great Laurentian geosyncline, apparently deeper in the northeast than in the southwest. Along the southern side of this trough east of Lake Huron occurs the very thick Grenville series of limestones, which becomes more and more metamorphosed, folded, crumpled, and elevated to the north. Through this trough at the north has broken a long northeasterly-southwesterly trending mass of granite, having the general direction of the present north shore of the St. Lawrence River, and followed on the north, not by limestones, but by sandstones and conglomerates (Adams). In the Lake Huron region and west of it, volcanic activity was very pronounced and lava streams, lapilli, and ashes occur on a large scale, either mixed with the water-formed sediments or making up thousands of feet of rocks in themselves. Much of the material suggests well-weathered products derived from granite and gneiss; but the arkoses, which are wide-spread and thick, probably imply a cool and moist land surface. All varieties of geological work seem to have been under way in Archeozoic time as they have been ever since; and there is no evidence of special primeval conditions different from those known to later geology (Coleman).

The most striking features of the Archeozoic formations are, then, that they are more largely igneous, and more profoundly and universally deformed and metamorphosed than those of subsequent eras (see Figs. 256 and 259).

Length of the Archeozoic. — That Archeozoic time was exceedingly long is evident from the thickness of the Grenville series alone, 94,000 feet, of which between 50,000 and 60,000 feet is marble.

Absence of All Fossils. — Of fossils there is no undoubted evidence, but that life, both of plants and animals, in at least the unicellular stage of evolution, was present seems to be attested, as previously discussed (page 546).

Mountain Building and Erosion Records

Laurentian Revolution. — After an exceedingly long era of tranquil events and the accumulation of vast depths of marine and some continental deposits, Archeozoic time passed into the closing stages, which were likewise of long continuance. The event of first importance was the Laurentian Revolution, marked by crustal unrest and disruption, not only throughout the Canadian Shield and North America, but possibly the world over. It is now known that almost everywhere over the shield the Archeozoic rocks were invaded by two series of Laurentian bathyliths of pinkish granites. These are seen almost everywhere at the surface of the shield. The first of these invasions was of closing Archeozoic time, but the second one is now considered to have been of early Proterozoic time. To keep these two important periods of intrusion distinctly apart, it is proposed to follow Van Hise and Leith, and Lawson, in retaining Logan's term Laurentian for the first granitic invasion and Algomian for the second (see Fig. 352).

"The first of the granites," says Barrell, "Lawson continues to call the Laurentian, the second great invasion he has named the Algomian, and he places it after the Huronian. Other writers, however, place the second before the Huronian; Coleman, moreover, considers it probable that the Laurentian of Logan's original area belongs to the later invasion, not the earlier, and the name refers more properly therefore to the later of the two. Such a conclusion leaves the earlier granite and gneiss nameless. In order to avoid confusion until more definite knowledge is attained, the writer proposes to call the older the *Paleolaurentian*, the later the *Neolaurentian*. Probably much of the fundamental granite gneiss for a long time, if ever, cannot be classified positively into either the one or the other division. For such areas the general name of *Laurentian* will continue to apply, and may include rocks of two widely different ages."

Laurentian Mountains. — The hot molten magmas welled from the depths of the earth and rose into the sedimentaries and volcanics of older date, re-melting and assimilating them in part, and raising them everywhere into the "domed mountains" or "bathylithic mountains" of Coleman. As geographic names are applied to mountains, these may be called the *Laurentian mountains*. These bathyliths, Coleman says, varied in length up to 60 miles, and were somewhat elongate from west to east or from southwest to northeast. This general east-northeast trend of the basement

structures doubtless reveals the axial relations of the Archeozoic mountain ranges. He thinks they probably were not continuous chains, but consisted rather of groups of domes of various sizes and heights. The thrusting came from the southeast, and it may be that because of this we can also see in these movements compensating ones leading to the origin of the Atlantic, or at least indicating the first known deepening of this ocean and the origin of the Interior epeiric basin.

With the rising of the Laurentian mountains went the arching, folding, crumpling, and metamorphosing of the Archeozoic formations. The Keewatin schists are now seen wrapped around the bathyliths, with dips in places of from 60° to 90°, but it should be remembered that what we now see are the combined results of three revolutions and a number of disturbances to be described in later pages. All of these movements were of pre-Cambrian time.

Ep-Archeozoic Interval. — While the Laurentian mountains were building and afterwards, erosion was at work degrading them, and on the basis of the marked unconformity existing between the Archeozoic and Proterozoic formations, it is clear not only that the interval was long but that the amount of erosion was great. How long this interval lasted and the amount of record removed is not known, but that the length of time was very great is evidenced by the fact that all geologists who have worked with the formations of the Canadian Shield are agreed that the greatest break in the pre-Cambrian formations occurs between the Archeozoic and Proterozoic systems of rocks. Van Hise and Leith say that in the Lake Superior area the Archeozoic was nearly base-leveled before the deposition of the Proterozoic. The contrast of the systems in vulcanism, in metamorphism, and in relative amounts of sediments is striking. Any one who has seen the evenly bedded Proterozoic sediments resting upon the erosion edges of the gnarled and contorted complex of Archean schists, gneisses, and other rocks would not question the conclusion that this unconformity is a great one and required for its development erosion throughout an eon of time.

CHAPTER XXVIII

THE EARLY PROTEROZOIC SUB-ERA

Extent and Thickness of the Proterozoic. — The Proterozoic era, or the time of first known life, represents a vast lapse of time, for in Ontario and the Lake Superior country it includes, as now defined, the making of a mountain system and its complete removal through erosion, with a maximum accumulation of about 74,000 feet of sediments and 22,000 feet of volcanics. Of these formations 20,000 feet of coarse detritus (coarse sandstones, conglomerates, and arkoses) were developed in the earliest part of the era, 25,200 feet of various kinds of sediments in the quiet middle time of main sea invasion, and 28,670 feet of coarse continental sediments, along with 22,700 feet of volcanics, in the troublous closing period. On the other hand, in the Rocky Mountains area, upward of 37,000 feet of sediments are still present, consisting mainly of sandstones and shales along with more than 7000 feet of limestones. For the distribution of the Proterozoic formations see maps, Figs. 348 and 356.

These events are grouped as follows, the oldest at the bottom:

Table of Proterozoic Events

Epi-Proterozoic interval of erosion.
Late Proterozoic sub-era, or Algonkian time.
  Late Algonkian time.
    Keweenawan series of continental formations.
      Break in record.
  Middle Proterozoic or early Algonkian time.
    Animikian marine series, with great iron formations.
    Epi-Huronian interval.
    Huronian series of glacial, continental and marine formations.
Early Proterozoic sub-era.
  Ep-Algomian interval, and formation of Laurentian peneplain.
  Algomian Revolution, mountain building, and second intrusion of Laurentian granites.
  Sudburian series of delta deposits.

Early Proterozoic Time

Huronian of Logan. — The original "Huronian system" of Logan has undergone much investigation since he studied it in the

eighteen-sixties and seventies, due to the great mining industries recently developed in Canada. It is highly to the credit of the later Canadian geologists that they have shown how vastly much more time is embraced in the Huronian system of Logan than was originally thought possible. In the past few years it has been learned that this time produced two distinct series of formations, separated from each other and from those below by periods of mountain building and of profound erosion. For this reason the Proterozoic is here divided into two sub-eras, though it is probable that future work will prove, as seems already indicated, that both are of era rank, and that the term Early Proterozoic will have to be given up for another in harmony with Archeozoic and Proterozoic. In this event the pre-Cambrian or "Archean" of older geologists will consist of three eras and not of two as presented in this book.

Fig. 350. — Vertical strata of Sudburian quartzite, near Whitefish, Ontario. Photograph by A. P. Coleman. From Yale University Press.

Sudburian Series. — This series of formations, apparently wholly of delta origin, attains to an estimated thickness of 20,000 feet and consists chiefly of white quartzites, which are well exposed from Lake Huron north to Sudbury, and beyond for 100 miles in Ontario (Fig. 350). These regularly bedded sands, mainly of vein quartz or the quartz of granites, about 15,000 feet thick, are cross-bedded throughout, with thin zones of interbedded slate, which represent from 2 to 13 per cent of the total thickness of the deposits. Carbonaceous material, however, is completely absent in the Sud-

burian, which is a cleanly washed sand of fairly equal grain, coming apparently from the north and transported by long rivers to a wide delta built into the epeiric sea that then lay over the United States.

The lower part of the Sudburian of Coleman, of variable thickness up to 5000 feet, is heterogeneous in composition. In places there are arkoses, the broken-up material of granite, as much as 1000 feet thick, and in others, regularly and cross-bedded thin alternations of grits and muds with angular quartz grains. The arkoses and graywackes full of feldspars are found in close association with areas of granite, and are therefore the disintegrated material of this old floor. As a rule, however, in most places the Sudburian has a basal conglomerate, which at Sudbury has a thickness ranging in places up to 5000 feet. The basal deposits include scales of

Fig. 351. — Sudburian quartzite, crumpled by granitic intrusions, near Cutler, Ontario. Photograph by A. P. Coleman. From Yale University Press.

chlorite or sericite in abundance, well-rounded pebbles and small boulders of several kinds of granites, vein quartz, quartzite, greenstone (metamorphosed volcanics), and banded jasper. These materials are from the older Laurentian granites and the Keewatin volcanics and iron deposits. The coarse basal fragmental material, in which the feldspars are undecomposed, is thought to indicate a cool and moist climate, though later Sudburian time may have been less severe.

At the top of the Sudburian occur very basic lavas with fine pillow structures. The dikes related to these flows cut all the

older rocks. These effusives, however, indicate a series of small volcanoes of no great geographic extent.

In places where the Sudburian is not intruded by the later eruptives, it is but little altered, so that the original bedding, cross-bedding, and even the ripple-marks may still be seen on weathered outcrops. Where intruded by the granites, however, the Sudburian is much metamorphosed. All of the Sudburian is deformed, tilted or sharply bent, with an average dip of 45°, the strata rising toward the granite bathyliths of later intrusion. For this reason, the Sudburian series is sharply marked off from the higher Huronian, which usually lies nearly flat or is but gently folded.

Similarity of Sudburian Formations to those of Later Eras. — As the Sudburian deposits are so very ancient geologically, it is consequently desirable to point out the physical conditions under which they must have formed. This has been done for us by Coleman, who states that except for the absence of fossils and the fact that in places they have been much metamorphosed, the rocks of Sudburian time resemble in every way the later sediments. Every type of rock has its counterpart in subsequent ages; and where the later rocks have undergone deforming stresses or have been penetrated by large masses of eruptives, as in various mountain regions, even the metamorphic characters of the Sudburian are found repeated in them, as in the Paleozoic schists. The apparently modern nature of the Sudburian is the most surprising impression made on the observer while in the field. From this we conclude that the atmosphere in character and composition must have resembled that of later times; water did its work then as now, the extremes of heat and cold seem to have been normal, and there is little doubt that plants and animals existed; in a word, the world was then organized along the lines which have been predominant ever since. There is no suggestion of the existence of primitive physical conditions radically unlike those which were to prevail in later times, and there is no evidence that the earth's internal heat was greater then than it is now.

Algomian Revolution. — After the close of Sudburian time came the second marked upwelling of granite bathyliths and the making of the Algomian mountains, so called by Lawson in 1913 from a locality in western Ontario. It seems that this second rising of granite from unknown depths was even more profound than the earlier one, the Laurentian, which gave rise to the Laurentian mountains at the close of the Archeozoic, as mentioned in the previous chapter. (See also Fig. 352.) How much of the Sud-

burian deposits was remelted and assimilated by the rising granites no one knows. The most recent writer on these formations and events, Coleman, concludes as follows:

"The sediments of the Sudbury, Temiscaming, Doré, and Seine series [which together make up the Sudburian] were upheaved, tilted, and thrown into folds along with the older groups of rock by the floods of granitic magma making up the Laurentian [of Logan]. From the attitude of their present remnants it is evident that great ranges of mountains with a trend of about N. 70° E. resulted from this enormous welling up of molten or plastic material. From the coarseness of the grain of the granites and gneisses enclosing or adjoining the sediments, it is evident that they cooled at great depths and slowly."

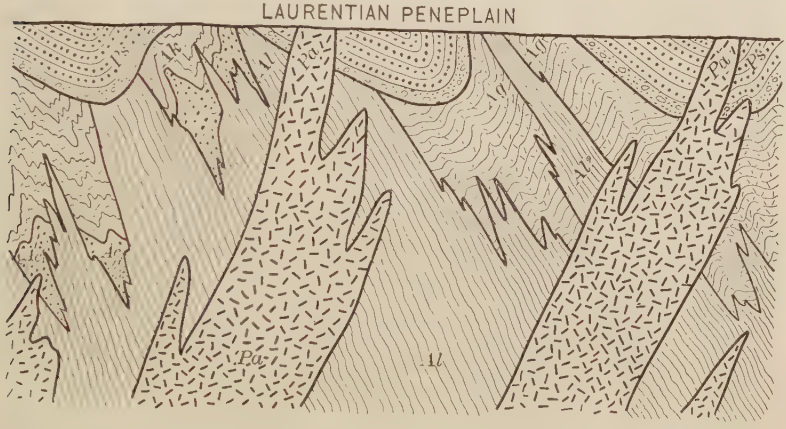


Fig. 352. — Diagram to show present relation of two series of granitic intrusions to older strata of Archeozoic and Early Proterozoic time. Drawn by Barrell. The order of events shown on the drawing is as follows, beginning with the youngest at the top: (7) Ep-Algomian interval and peneplanation; (6) Algomian Revolution, granitic intrusions (*Pa*), and folding of Sudburian (*Ps*); (5) Sudburian sedimentation (*Ps*); (4) Ep-Archeozoic interval and peneplanation (heavy line at base of *Ps*); (3) Laurentian Revolution, granitic intrusions (*Al*), and folding of Archeozoic formations; (2) Keewatin lava outflows (*Ak*), and Grenville sedimentation (*Ag*); and (1) Coutchiching sedimentation (*Ac*).

Granite Injections. — Though granites dominate the rocks of the Archeozoic and Early Proterozoic formations the student must not conclude that they are restricted to these times. Granites are known in the hearts of the mountains of almost any date (see page 364), though they are exposed less in those of Cenozoic time than in those of older age, partly because of the shorter time the Tertiary rocks have been subjected to profound erosion.

Ep-Algomian Interval. — After the Algomian mountains had been built, their destruction followed, and their removal by erosion must have been an extremely slow process. Coleman states that thousands of feet of granite, gneiss, greenstone (metamorphosed basalt), quartzite, and schist conglomerate must have been consumed by the weathering processes. The Algomian mountains, occupying most of the Canadian Shield, were during this interval carved down to a peneplain, laying bare the roots of the mountains; this is the most tremendous and wide-spread example of base-leveling known in the history of the world. The erosion which has since taken place over the Canadian Shield is insignificant in comparison, so that the present peneplain is in part a close approximation to this ancient land surface. How vast a time was required for the removal of millions of cubic miles of hard rock from this great area (the shield has an area of 2,000,000 square miles, see Fig. 365), and whither the material has been transported, one can scarcely guess, though it seems probable that it lies deeply buried in the oceanic basins.

Laurentian Peneplain

Original Character of the Peneplain. — The present surface, Coleman says, "is a close counterpart of that on which the Huronian was deposited and from which in places its basal conglomerate is now being stripped. In fact, it almost appears as if the present uneven plain of comparatively low relief, formed everywhere of mounds or ridges and depressions, is part of the little changed pre-Huronian continent. . . . It looks as though far the greater part of the peneplanation was already complete in Huronian times." It should be added, however, that much of the surface had been repeatedly covered by the sea, even as late as Devonian time, and that the last of this covering has been removed only comparatively recently. Other parts not so protected by later Proterozoic or Paleozoic sediments must have had the pre-Huronian surface destroyed during those ages. Since no pronounced warping or folding has since taken place, however, these various facets of erosion of the present surface developed in various periods must shade into each other. The recently exposed pre-Huronian peneplain occupying wide areas around the basal Huronian might properly be called the Ep-Algomian facet of the Laurentian peneplain. Coleman continues, "The basal Huronian conglomerate has perfectly sealed up and preserved for us parts of the ancient surface. At some points the rock beneath had been weathered in

place, and one can observe the fresh, unbroken material growing fissured in the upper parts and passing into a breccia of fragments and finally into coarse sand, all now firmly cemented into rock."

"The surface beneath the Huronian represents therefore a mountain region degraded by subaërial forces to a peneplain, somewhat hummocky and irregular, but in the main of low relief [see Fig. 353]. In many, if not in all places, its surface was deeply mantled with the disintegration products due to this secular decay, but before the deposition of the Lower Huronian some parts had not only been swept bare of débris but had been scoured and smoothed to the solid rock."

Fig. 353. — Laurentian peneplain as seen from Lake Michikamau, Labrador. Photograph by A. P. Low. From Yale University Press.

Present Character of the Canadian Shield. — The greater part of the present surface of the Canadian Shield (see map, Fig. 365) is an undulating plain replete with an intricate series of connected lakes and rivers (Fig. 353); near the center of it lies a depressed area containing Hudson Bay, a body of marine water with an average depth of 420 feet. From this central basin there is an upward slope in all directions toward the Height of Land. The general level of the plain above the sea is about 1500 feet, and the local differences of level are usually under 150 feet, though rarely they may be as much as 500 feet above the general plain.

The shield as a whole rises slowly to the east, and in central Ungava is about 2400 feet above the sea. Along the eastern margin of Labrador are rugged mountains that in the north attain to 6000 feet, and certain peaks even reach 7500 feet. In fact, it may

be said that a mountainous tract extends for 2000 miles from Belle Isle north to Cape Sabine in Smith Land. This rough topography, and also that along the southern margin east of the city of Quebec, is youthful in form, and the deformation of the shield here is thought to have arisen in late Tertiary or early Pleistocene time, the movements continuing to recent times.

Suess would limit the shield to Canada, as above defined, but Adams and other geologists include in it Greenland and the Adirondacks of New York. The latter region now reaches a height on a few mountain peaks of about 5000 feet above the sea, the average elevation being about 2000 feet, an altitude which is also the result of Cenozoic upheaval of a regional character.

Geologic Structure of the Canadian Shield. — Most of the shield, in fact it is said four fifths of it, is composed of gneisses and gneissic granite, the rocks of Logan's Laurentian system. There are, however, according to Adams, "distributed over the surface of the shield, chiefly in the form of long and relatively narrow belts, certain very ancient sediments, pre-Cambrian in age. These belts occupy the position of synclinal folds which have sagged down or have been forced down into the igneous rocks of the Laurentian which surround and underlie them. These belts in the southern half of the shield have a prevailing northeast and southwest strike, indicating the trend of ancient folds, which probably developed as mountain ranges in pre-Cambrian times, having a general direction parallel to the present course of the river and gulf of St. Lawrence. One of the longest, best defined, and most striking of these folds is the geosyncline, which, starting from the north shore of Lake Huron, extends past Lake Temiscaming, Lake Abitibi, to Lake Mistassini, and thence on in a northeasterly direction till it is lost in the unexplored portion of Labrador peninsula. The original Huronian area of Logan lies in this belt."

Origin of the Central Interior Basin

We have seen that at various times during the pre-Cambrian the Canadian Shield was extensively deformed and broadly though slightly elevated. The same is true for the eastern and western border lands, Appalachia and Cascadia, but the great medial southern part of the continent seems not to have been so affected. It continued a low-lying area, a continental basin that stood but little above the average sea-level (see Fig. 365). Wherever this basin has subsequently been upwarped and the Paleozoic forma-

tions removed through erosion, there are revealed the same kinds of rocks as those of the shield. From this it appears that the Canadian Shield, Appalachia, Cascadia, and Columbia have been as a rule positive in their movements (see page 228 and Fig. 185), while the continental basin has only been subpositive or stationary. With the introduction of Paleozoic time the continental basin appears to have been more negative, for we shall see it repeatedly covered by the shallow Central Interior sea, but the average depression for all of Paleozoic time did not exceed 2000 feet. This is more especially true of the region west of a line extending from Sandusky to Cincinnati, Ohio, and thence to Nashville, Tennessee.

CHAPTER XXIX

THE LATE PROTEROZOIC SUB-ERA

Early Algonkian Time

Late Proterozoic time is replete with interest because at the very beginning of this sub-era we have not only unmistakable evidence of a glacial climate, but also the first positive evidence of plant life in the form of calcareous algal secretions. The divisions of Late Proterozoic time are shown on pages 444 and 551.

Definition of Algonkian. — Late Proterozoic time may also be known as *Algonkian*, a term used in a wider sense by the United States Geological Survey for the " sedimentary formations and their metamorphosed equivalents with associated igneous rocks beneath the Cambrian and resting upon the Archean complex " (Van Hise and Leith). At the time the name was proposed, there was thought to be a sharp distinction between the earlier era, the Archean, characterized by dominance of igneous rocks, and a later one, having in the main sedimentary deposits. The recognition, however, of a second great granitic invasion, and the further fact that igneous rocks alternate with periods of sedimentation as far back as geologic history is known, largely destroy the value of the divisions Archean and Algonkian. The latter name has reference to the land of the Algonkian Indians — the Lake Superior-Ontario-Hudson Bay country — where these rocks have long been studied.

Basal Tillites of the Huronian. — One of the most surprising of recent discoveries in Geology was the finding by Coleman of tillites (morainal deposits of glacial till or bowlder clay, hardened into stone, see page 134 and Fig. 354) in the Huronian formations of Canada, and the consequent establishing of the occurrence of a *glacial climate* thus early in the history of the earth. Over the wide Laurentian peneplain just described, there is found in the country to the north of Lake Huron a basal conglomerate that often includes facetted and striated bowlders of various kinds of rocks (Fig. 355). In the tillites occur, locally, thick zones of slate and water-formed conglomerates and quartzites that indicate interglacial warmer climates.

Fig. 354. — Eroded exposure of the Lower Huronian tillite, near Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

Fig. 355. — Striated bowlder of the Lower Huronian tillite, Cobalt, Ontario. Photograph by A. P. Coleman. Yale University Press.

The whole thickness of glacial beds is usually not more than 500 or 600 feet, somewhat in excess of the thickness of the recent Pleistocene glacial and interglacial beds at Toronto. This Huronian tillite is known to cover an area of 1000 miles from west to east and 200 miles north and south, down to 42° north latitude, and rests upon a nearly plane surface that still lies not far above sea-level. It is the material of a continental ice sheet which deposited its content of rocks and earth upon the land.

"Bowlders of granite and greenstone with diameters up to 2 or 3 feet are common and larger ones measuring 5 feet through are occasionally met. . . . These bowlders may be well rounded, subangular, or angular. They may be crowded into a mass of large and small stones cemented together, or they may lie sparsely scattered in a fine-grained matrix, the red granites showing up sharply from square yards of dull greenish gray ground mass. Generally no marked stratification can be seen in the coarser conglomerates, though associated pebble conglomerates and slates may be well stratified. . . . The matrix and the bowlders enclosed vary greatly from point to point, roughly corresponding to the character of the rocks beneath, and the rock strongly suggests a glacial moraine in some cases and bowlder clay in others." (Coleman.)

Huronian Sedimentaries. — Above the basal tillites occur gray quartzites that rarely are conglomeratic and attain to 1000 feet in thickness. Then follows a marine limestone about 300 feet thick, and this limestone in the Lake Huron region is thought to be of the same age as another limestone, blue and gray in color and up to 500 feet thick, situated at the base of the Huronian series in the Rainy Lake area north of Minnesota. The latter limestone bears the oldest undoubted fossils known, certain forms of calcareous algal secretions, of which more will be said later.

Over the limestone of Lake Huron appear arkoses reaching 2300 feet in thickness, followed by 2150 feet of red jasper conglomerates, 2970 feet of white quartzite, 400 feet of chert with limestone and slate, and 1500 feet of white quartzite. These deposits are thought to be those of a delta, and the arkoses and green quartzites suggest a cool and moist climate following the Huronian ice age.

There appears to have been no volcanic eruption in Huronian time.

Epi-Huronian Interval. — The Huronian was not followed by a time of mountain building, but by slight bodily elevation or warping. The land condition of the shield thus brought about is thought to have been of long duration, and Lawson believes it of great enough importance to be called the *Ep-Archean interval.* In point of fact, however, it may be said that, although the Canadian Shield has undergone many movements, none of them after the Algomian Revolution was of a marked character until that of

the recent Pleistocene time, when the eastern and southwestern borders underwent elevation, as is now to be seen in the young topography of the areas mentioned.

Animikian or Iron Series. — The formations of Animikian time have a wide though scattering distribution over the Canadian Shield, the sea, it is thought, having transgressed far and wide over the older rocks. Most of the deposits are of marine origin, though some appear to be of a continental character. However, the Animikian formations are not now of universal distribution over the shield. On the contrary, the areas are widely isolated

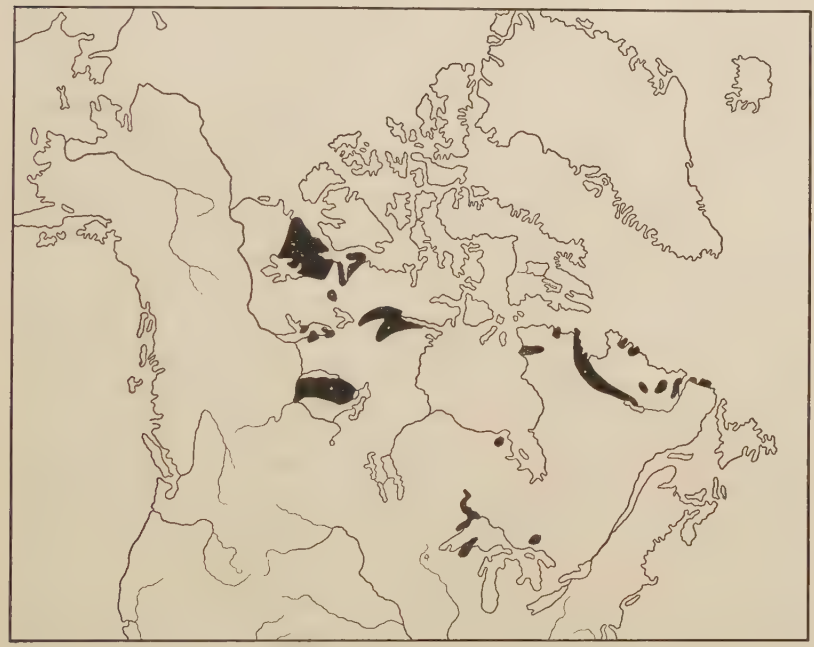


Fig. 356. — Surface distribution of the known Animikian and Keweenawan formations. After Coleman. Yale University Press.

and appear in the main to be remnants preserved from erosion in the down-folded or gently down-warped basins in the older rocks (Fig. 356). The bounding lands of these seas are as yet unknown.

Everywhere the Animikian strata lie nearly horizontal and are very little metamorphosed. In the Penokee area of Michigan the formations that remain after their long exposure to the erosive forces are still 14,000 feet thick, but elsewhere they are usually reduced to a maximum of about 6000 feet.

The deposits of the Animikian may begin with a basal conglomerate of pebbles of the Keewatin schist and Laurentian gneiss. This passes into chert or jasper that may be banded or oölitic, or into beds of impure limestone or dolomite with chert. Higher in the series there are great thicknesses of thinly laminated carbonaceous slate with large concretions of marcasite, and it has been calculated that if all of the carbon in these argillites (6 to 10 per cent) were concentrated, it would make a bed of anthracite 200 feet thick. There is also much sandstone. Near Port Arthur the Animikian is interbedded with sills and dikes of diabase or trap of Keweenawan age, the sills varying from an inch up to 200 feet or more in thickness, and near Sudbury there are interbedded tuffs with a depth of 3800 feet.

"The wide-spread shallow seas of the Animikie," says Coleman, "had one feature scarcely repeated on the same scale in later times, the deposition of iron compounds with associated silica. In nearly all of the Animikie areas there is an 'iron formation' [in places as much as 1000 feet thick], with cherty ferruginous carbonate or oölitic greenalite or jasper . . . as the initial stage, from which are formed by secondary causes small or large bodies of ore, culminating in the immense and rich deposits of the Mesabi to the southwest of the shield in Minnesota." Other great fields occur in the Penokee-Gogebic region of Wisconsin and Michigan, and in the Menominee area, which lies chiefly in the latter state.

Lake Superior Iron Mines. — The hematite ores found along the south and west sides of Lake Superior in the Archeozoic and Proterozoic formations are in the main (70 per cent) from the Animikian series. Most of the richest ores occur near the surface and for 1000 feet downward. Originally the iron formation had a content of about 25 per cent of metallic iron, but in places it has been concentrated and in these, which form the mining areas, the amount in the ores now mined is about 59 per cent. The Marquette, Michigan, field was opened in 1849, and that of the Mesabi in 1892. In 1912 Minnesota produced more than 34,000,000 long tons and Michigan about 11,000,000, making up about 82 per cent of all the iron-ores mined in that year in the United States. On account of the enormous scale upon which these rich mines are now worked they will become exhausted during the present generation. Vast bodies of lower grade ores remain, however, which will gradually come into economic use, but their lower content of metal will mean, in so far as that factor is concerned, a higher price of iron. The rich ores utilized in the present generation have been no small factor in the present great industrial expansion of the United States and Canada.

Late Algonkian Time

Lower Keweenawan Sediments. — Geologists are agreed that there is a distinct break in the record between the Animikian and the Keweenawan series of formations. Moreover, the sediments of the former are of marine origin, while those of the latter are held to be of continental deposition. Some geologists hold that the

Keweenawan should be referred to the Paleozoic, but the trend of opinion is that it should be regarded as the closing period of the Proterozoic era, a belief that is followed in this book. The Keweenawan is characterized by enormously thick deposits, both of sediments and lavas, in geosynclines, and also rather widely over vast areas. The igneous activity became greater in its middle and upper portions.

At the base, from Wisconsin eastward, there are conglomerates, well stratified, coarse, red and white sandstones interbedded with conglomerates, thin impure limestones of various colors, and shaly rocks, the whole having a thickness of from 300 to 1400 feet. These are also penetrated by dikes and sills of diabase or trap of Upper Keweenawan time. The sediments are largely derived from the Laurentian granites, but red jasper pebbles of the iron formations also occur. Ripple-marks are common, the sandstones are often feldspathic and might be called arkose, and the shales have mud-cracks, all of which are indicative of continental origin. Further, the prevailing color is red, like the Triassic of the Connecticut valley, suggesting semiarid conditions and complete oxidation, and in this, according to Van Hise and Leith, the Keweenawan sediments differ greatly from the earlier series; the absence of carbonaceous beds is also strikingly different from the conditions found in the Animikie sediments.

Upper Keweenawan Volcanics. — The closing period of the Proterozoic record is marked in the region of Lake Superior and elsewhere by a tremendous outpouring of volcanic materials upon the dry land, probably not by volcanoes but rather through fissures. Most of the formation, according to Coleman, " consists of basic lava flows, variously called trap or diabase or melaphyre, some being really basalts, but there are also more acid [feldspathic] flows, referred to as porphyries and felsites, really rhyolites. In subordinate amounts ash rocks and lapilli are found between the lava sheets, and the [interbedded] conglomerates and sandstones [and shales of small amounts] are made of almost contemporary material, especially of fragments of the rhyolites and porphyries." It is very difficult to decide whether the eruptions of Keweenawan time were greater than those of Keewatin.

One of the thickest series of lavas known on the Canadian side of Lake Superior occurs on Michipicoten Island where a section was measured with a thickness of 11,230 feet, only a small part of which consists of sediments. In northern Wisconsin and Michigan, Van Hise and Leith give the maximum thickness of their

Middle Keweenawan (after allowing for initial dip during accumulation) as upward of 30,000 feet. Of this, from five eighths to eight ninths is igneous material, the rest being red conglomerates and red sandstones derived from the volcanics.

Over the "Middle Keweenawan" of Wisconsin and Michigan lies the local "Upper Keweenawan," made up of conglomerates (800 to 4000 feet), sandstones (15,000 feet), and shales (100 to 400 feet) attaining a total thickness of about 20,000 feet. All of this material is, however, detritus from the igneous Keweenawan, and does not signify a long interval of erosion, because of the soft nature of the volcanics and the high and rough topography of the lava field. However, Van Hise and Leith say that Keweenawan time may have been as long as the Silurian, Devonian, or even the Cambrian.

The volume of known igneous material extruded (estimated as 24,000 cubic miles) was accumulated in a sinking field, and in this way arose the Lake Superior geosynclinal basin, which is almost devoid of subordinate folds. In other words, the molten material as it rose to the surface permitted the upper formation to sink in. In other areas, however, the Keweenawan rocks still lie almost horizontal, and in general their appearance is not unlike similar Paleozoic formations, though block faulting is common.

Upper Keweenawan Metals. — From the human and economic point of view, the advent of the Keweenawan lavas was one of the most important events in the pre-Cambrian history of the Canadian Shield, since most of the valuable ore deposits of the region, so far as known, are connected with eruptions of this age. At Thunder Bay the *silver ores* of Silver Islet and other mines were supplied by the Keweenawan diabase dikes and sills. The unrivalled mines of *native copper* in Michigan belong to the amygdaloids and conglomerates of Keweenaw Point, and similar ores of native copper, perhaps on a larger scale, exist in the extensive area of amygdaloids east of Great Bear Lake and near Coppermine River in the extreme north of the shield. (Coleman.)

The native "low grade" copper ore of Michigan was discovered by Douglas Houghton in 1830, though worked long before by the Indians. The area in which it occurs is 70 miles long by 3 to 6 miles wide. The famous Calumet and Hecla mines were opened in 1846, and in the following year Michigan produced 213 long tons of copper. In 1911, the yield was 110,000 tons, valued at $27,480,000.

"The Sudbury [Ontario] deposits of *nickel and copper*, including much the largest mines of nickel in the world, are connected with a sheet of norite-micropegmatite probably of Keweenawan age; and Miller has concluded that the singularly rich silver veins of

Cobalt have derived their ore from a great diabase sill which ascended into the Cobalt conglomerate at this time.

"The Keweenawan eruptives seem to have brought with them copper, nickel, and silver in large amounts, cobalt, gold, platinum, and palladium in much smaller amounts; and if the iron mines are left out of account, almost all the metalliferous deposits of the southern margin of the Canadian Shield have resulted from the coming of its dikes or sheets or lava streams." (Coleman.)

Fig. 357. — Limestones and cherts of the Proterozoic (Castle Mt. group), Flathead County, Montana. Photograph by Walcott, U. S. Geol. Surv.

Proterozoic of the Cordilleras

The best known and thickest sections of Proterozoic formations in western North America occur in western Montana, eastern Idaho, and British Columbia, north to at least 54° north latitude (see Fig. 357). Upward of 37,000 feet of sediments, mainly sandstones and shales, are exposed in the combined sections. In the Cabinet Range, Montana, the thickness is about 35,000 feet (Calkins). A striking feature of the Proterozoic formations of the Cordilleras, Lindgren states, is the small amount of igneous materials. Diabase intrusions of small areal extent are known, and it is probable that there are also some basalt flows. North of the Inter-

national Boundary, however, extensive intruded sheets are referred to this period.

The Cambrian overlies the Proterozoic strata in Montana and British Columbia with apparent conformity, and yet there may have been as much as 16,000 feet locally removed through erosion preceding the overlap mentioned. In the lower part of these sections occur three great limestones, pure and impure, that have thicknesses ranging between 2000 and 4800 feet. It is in these calcareous zones that lime-secreting algæ abound. The bulk of the sediment, however, is sandstone, and it is significant that above the basal portion much of it is red in color, ripple-marked, and sun-cracked. As the clastic portion thickens to the west at the expense of the limestone, we see that it is from this direction that the sediment was mostly derived. The inference seems to be that the earlier sediments are of marine origin, while the later formations are either delta deposits or are continental and of a semiarid climate. From this it appears that the succession harmonizes well with that of the Middle and later Proterozoic of the Canadian Shield. All of these vast piles of rock came from a land which then included California and the region north into western British Columbia.

Fig. 358. — View east up Colorado River, near mouth of Bass Canyon, Arizona. The print is the reverse of the view in nature. On the left and above are horizontal Paleozoic strata resting on peneplained monoclinal beds of the Proterozoic (Unkar). The latter lie upon the tilted and peneplained Archeozoic (out of view) in the Granite Gorge of the river. Photograph by L. F. Noble.

In the *Grand Canyon*, Arizona, occur the Chuar and Unkar formations with a thickness, remaining after an unknown amount of erosion, of nearly 12,000 feet, most of which is sandstone, while of limestone there is only 435 feet, and that near the base. The sediments are at first of marine origin, but quickly pass upward

into continental deposits (Fig. 358). These formations rest on the peneplained surface of the highly deformed Archeozoic strata, and both were again elevated into mountains and eroded to sea-level before the Paleozoic era began, for the horizontal Cambrian strata rest upon the peneplained older formations. In other words, after the deposition of these deposits of Proterozoic time, the rocks of the Colorado plateau were profoundly folded and elevated into a monoclinal attitude, and the resulting mountains were presumably as high as the present Alps. How long it will take to reduce the Alps, with the Matterhorn standing at 14,780 feet above the sea, no one knows, and yet it probably took as long, late in Proterozoic time, to remove the monoclinal mountains of western Arizona. The length of this time is now indicated by a marked unconformity, and as the movement falls in a time of world-wide deformation, it may be known as the *Grand Canyon Revolution* (see Figs. 34, 35, 349 and 358).

Close of the Proterozoic

Epi-Proterozoic Interval. — Erosion intervals and unconformities are of very variable duration in the different areas of the lands. They may be so short that geologists have the greatest difficulties in discerning the breaks, and on the other hand they may appear as if embracing nearly all of geologic time. It is of common occurrence on the Canadian Shield to find the Archeozoic formations overlain by the almost recent Pleistocene glacial deposits, and even these may be absent. It appears as if in such places no rocks had been deposited, either by the sea or by the forces of the land, since Archeozoic time, and yet geologists know that the shield has been variously covered by sheets of sediments formed at sundry times in the Proterozoic, Paleozoic, and, to a more limited extent, in the Mesozoic.

We have seen that some geologists refer the Keweenawan to the Paleozoic, but most workers hold that the formation of this series was the latest event in the Proterozoic, and that a long interval of time is unrecorded between it and the oldest deposits of the Cambrian. Further, in most places on the shield the Keweenawan was never laid down, and the Animikian and even the Huronian may have been eroded away before the seas of Cambrian time again invaded the area. Therefore, the Epi-Proterozoic interval is locally very variable in its apparent duration, but from the standpoint of the ascertained geologic record in its most complete form, it does not seem that this break can be more important

than the similar ones between the other eras. Accordingly, we may say that the interval appears to have lasted long, but as there are so few late Proterozoic fossils at hand, and therefore no record of organic evolution to guide us, the length of the interval cannot even be hinted at, as yet.

Lipalian Interval of Marine Organic Evolution. — Walcott, from his studies of pre-Cambrian formations, believes that nearly all of the Proterozoic deposits are not of marine origin, but that only at rare intervals did the oceans flow over the continents and thus bring into the seas of the lands their shallow-water life. Accordingly, he postulates the *Lipalian era* "of unknown *marine* sedimentation between the adjustment of pelagic life to littoral conditions and the appearance of the Lower Cambrian fauna. It represents the period between the formation of the Algonkian continents and the earliest encroachment of the Lower Cambrian sea."

It is hard to accept this postulate, since marine animals are known of latest Proterozoic time, and in addition these formations at many horizons have *algæ*, or seaweeds, as fossils. Since marine organisms are known and the limestones are of great thickness, there is evidence that marine waters (not necessarily as salty then as now) did for long periods of time invade North America. The Huronian seas, however, spread less widely than those of Animikian time.

Apparent Absence of Lime-secreting Animals. — The apparent absence of animals in the Proterozoic has been explained as possibly due to a lack of the proper amount of lime salts in the oceans and seas of this early era. In other words, it is held that there was no lime available for organic skeletons and hence there could be no structures that were preservable as fossils. Daly has suggested that the small amount of lime then being delivered by the rivers to the seas was quickly precipitated through the continuous decay of organisms. However, that lime salts were present in usable form for the making of organic structures is proved by the massive calcareous algæ recently discovered. That the marine waters of this ancient time may have had a different salt content, as held by Daly and Lane, and that this difference led to different physiological processes among the organisms, preventing the invertebrates from using lime in their skeletal parts, is more probably true, but that it is not the whole truth is seen in the fact that plants at least did build skeletons of carbonate of lime, while animals had chitinous coverings.

Proterozoic Climates

We learned on page 560 of the wide-spread glacial tillites in the Province of Ontario which are of the age of the earliest Huronian. This evidence, interpreted in the light of the knowledge derived from the most recent glaciation (Pleistocene), seemingly indicates a cold climate at this time for most of the world (see map for distribution, Fig. 359).

Another series of undoubted glacial tillites occurs in southern Australia and Tasmania, having a thickness of between 600 and 1500 feet. These lie just below Lower Cambrian deposits and are held to be of latest Proterozoic time. Other glacial tills, also

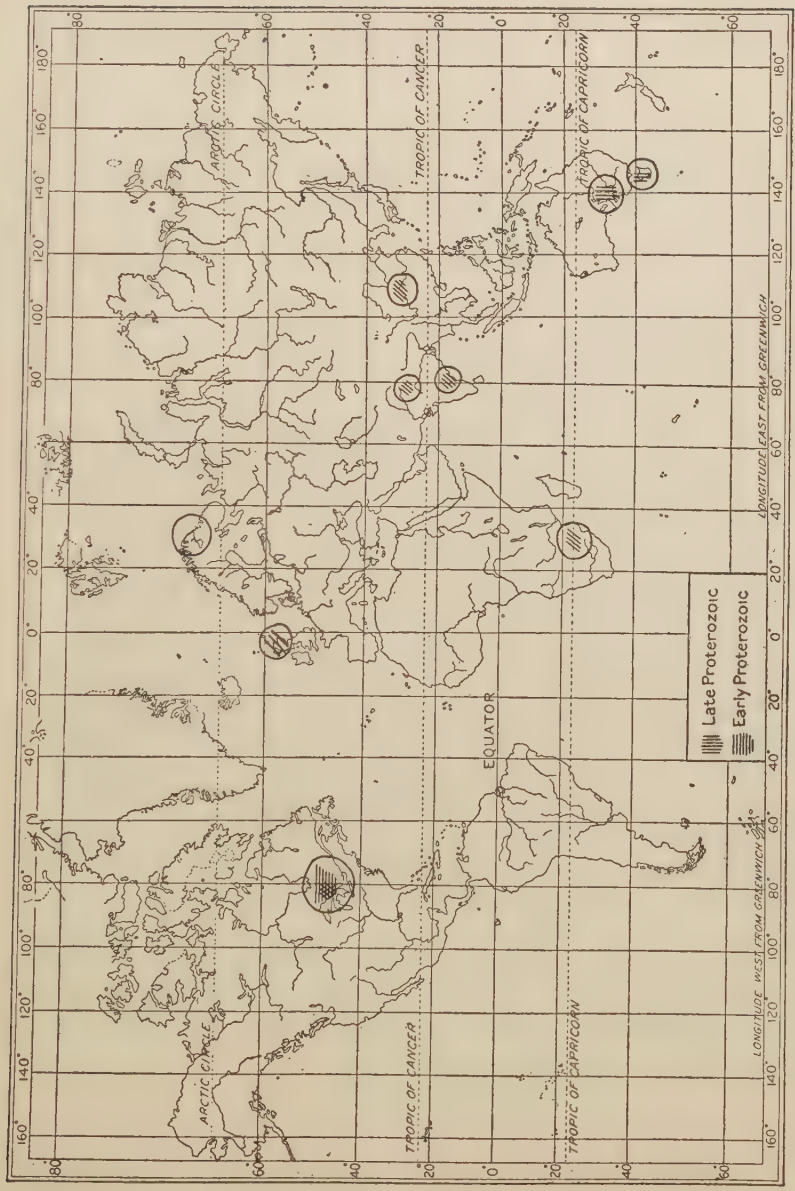


Fig. 359. — Areas of Proterozoic glaciation. Diagonal lines are areas of unknown age. The Norwegian occurrence shown by an empty circle is probably of late Proterozoic time. Carnegie Institution.

thought to be of late Protorozoic time, were made known by Reusch as long ago as in 1891, in the north of Norway, where is also preserved the scratched ground over which the ice moved. Therefore the evidence seems to indicate another cold climate for the world during the latest part of Proterozoic time.

Still other Proterozoic tillites are known in peninsular India, at Simla in northern India, and again in southeastern Africa. Finally, in China, in the provinces of the middle Yangtse River, Willis and Blackwelder have discovered unmistakable tillites. The exact age of all these occurrences is not yet established beyond the fact that they appear to be of Proterozoic time; probably some of them are of one age.

On the other hand, the very thick beds of Proterozoic limestone suggest that at the time of their formation the climate was at

Fig. 360. — Proterozoic reef of calcareous algæ (*Collenia? frequens*), Flathead County, Montana. Photograph by Willis, U. S. Geol. Surv.

least mild. We may, therefore, conclude that at this very early time in the geologic history of the earth the climates were in general of the same nature as they have been ever since. That is, this and other evidence indicate that during long stretches of time the temperature of air and water was mild and fairly uniform the world over, but that at somewhat irregular intervals cold climates developed that were geologically of short duration. The times of reduced temperatures appear to coincide with the beginning or close of the eras.

Life of the Proterozoic

It is not so long since it was thought that the Proterozoic strata were devoid of recognizable fossils, but during the past fifteen years Walcott has described such from various places and Cayeux has secured undoubted Radiolaria (Fig. 330), and possibly Foraminifera (Fig. 328), from Brittany in France. A careful search among the Proterozoic flints would probably reveal more of these, and one through the limestones might yield undoubted Foraminifera and possibly other micro-organisms.

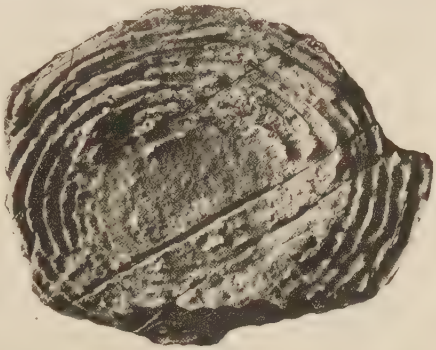


Fig. 361. — Single head of an alga (*Newlandia concentrica*), from the Belt series, Montana. $\times \frac{2}{3}$. After Walcott.

The most abundant fossils of the Proterozoic limestone strata are the secretions of *calcareous algæ* commonly known as *Cryptozoön* (Figs. 360–362). These coral-like plant masses make entire beds that repeat themselves time and again through thousands of feet of limestone; and,

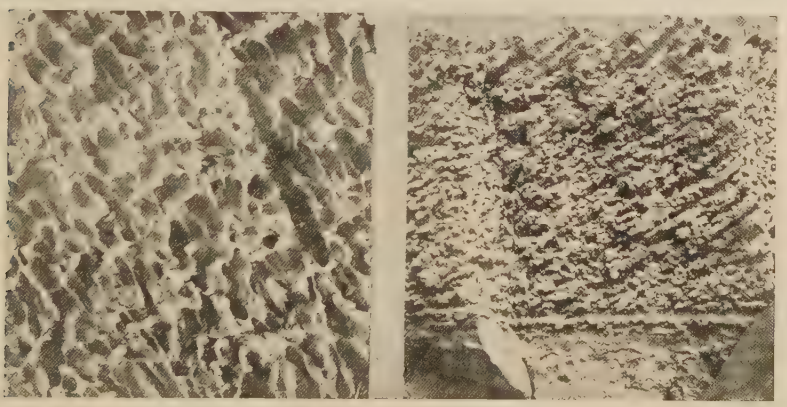


Fig. 362. — Internal structure of a Proterozoic alga (*Camasia spongiosa*), from the Belt series, Montana. About natural size. After Walcott.

while they may never be of value for detailed correlation, they will help toward establishing the zones of the Proterozoic.

Walcott has recently shown that certain of the Proterozoic (Belt) limestone formations abound in a variety of layered secretions due to the physiological processes of algæ (blue-green) living in water with lime salts in solution. One of

these forms has long been known as *Cryptozoön*. Walcott now describes them under six new genera and ten species. Most of them occur in abundance in the Newland limestone in Montana throughout a thickness of 2000 feet. Higher up come the Greyson shales, 3000 feet thick, with marine annelids, but without the algæ. Still higher are the Spokane shales, 1500 feet thick, and here again in a thick zone the algæ abound. We may, therefore, truthfully say that the Proterozoic strata of the Cordilleran region abound in fossils, but not in such forms as would be expected from the evidence of the Paleozoic formations. It is rather a plant world of the lowest type, that has left inorganic structures from which but little of the original organisms that caused their formation can now be learned. The progenitors of the Paleozoic marine faunas are still to be discovered.

A further interesting discovery was made by Lawson and Walcott in 1912 when they secured an abundance of fossils, probably also algæ (*Atikokania*), in a Huronian limestone over 500 feet thick at Steeprock Lake, west of Port Arthur, Ontario. These fossils are cylindrical or cornucopia-like to semiglobose bodies from 1 to

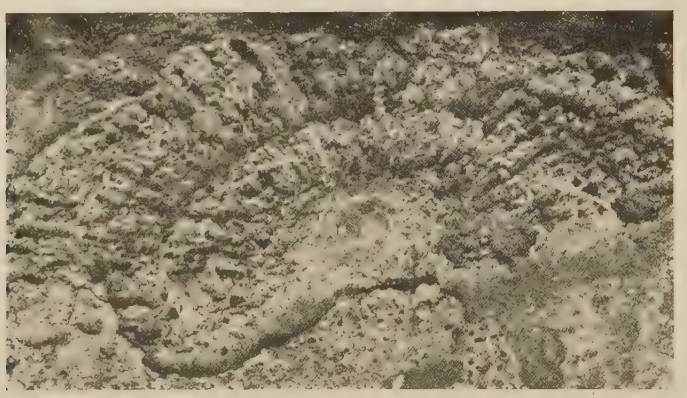


Fig. 363. — Weathered section through an alga (*Atikokania lawsoni*). × 2. Geol. Surv. Canada.

15 inches in diameter and height (Fig. 363). The solid structure is very thick and is traversed by an abundance of comparatively large radiating canals; in general it is like that of other Proterozoic algæ.

From the upper portion of the Proterozoic (Belt series) of Montana, Walcott has described a number of *worm burrows and trails*, seemingly of segmented annelids, that were found 7700 feet beneath the top of the section (Fig. 364). They are among the youngest fossils known in the Proterozoic, and even though they are only burrows and trails they seem to indicate the presence here of free (errant) annelids, a class of marine invertebrates high in the line

of organic evolution. There are still other fossils, but their nature is too obscure to make out their relationship to known organisms.

This evidence shows not only that life was present very early in the Proterozoic but that it had been existent for a long time previously, as proved by the calcareous algæ, marine plants that are, it is true, still primitive in organization and yet are greatly advanced over their more primitive progenitors. Finally, in the later

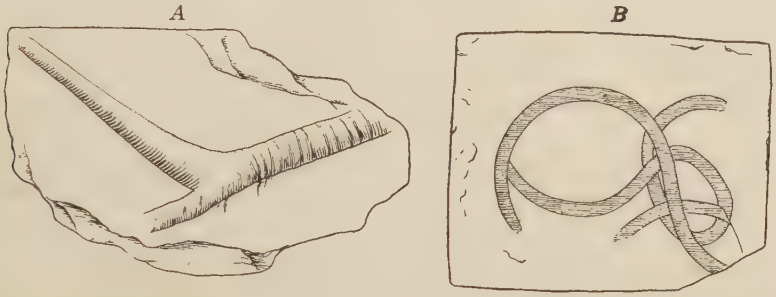


Fig. 364. — Burrows of Proterozoic worms. *A*, cast of large burrow (*Planolites corrugatus*). *B*, imprint of the actual annelid tube (*Helminthoidichnites meeki*). After Walcott.

Proterozoic, occur the Protozoa, a class of organisms represented by the Radiolaria, and here are also found Annelida. This means that most of the invertebrate classes of organisms other than the highest phylum (Arthropoda) were then in existence.

The above direct evidence of life in the Proterozoic also establishes the indirect testimony as to the abundance of organisms, even though lowly, which were necessary to have made the limestones, carbonaceous shales and iron-ores, not only of this era, but of the Archeozoic as well.

CHAPTER XXX

THE PALEOZOIC ERA

Comparison of the Paleozoic and Older Records. — With the beginning of Paleozoic time the strata are far less disturbed and have an abundance of fossils. Accordingly, there is at hand a ready and reliable means of correlating the formations not only from place to place but even between continents. Hence we have in most post-Proterozoic strata a far more detailed classification of the events, and also a greater knowledge of two parallel evolutions, that of the rocks and that of the organisms. As these two sets of phenomena are constantly interacting, they are checks upon each other in the determination of the actual events which happened at any time at a given place. In other words, because of the abundance of fossils in the Paleozoic and subsequent times, we have a ready means of deciphering a much more detailed history of the earth and its life than is the case in the earlier though far longer chronology.

North America: the Type Continent

Definition of Continent. — Dana long ago well said: "America is the type continent of the world." North America *is* the type continent, because of its simplicity of geologic structure, not only throughout its vast extent but also throughout the geologic ages. The other continent of the northern hemisphere, on the contrary, is more complex in structure, since only in the course of time, through the welding together of several land masses by orogenic (mountain-making) forces, has Eurasia been formed. A typical continent, Dana states, is "a body of land so large as to have the typical basin-like form, — that is, independent mountain chains on either side of a low interior."

Canadian Shield. — A great part of the northern half of North America comprises the Canadian Shield, described in foregoing chapters (see also Fig. 365). As we have seen, there is here revealed the greater part of pre-Cambrian history, events which took an immense lapse of time to accomplish, and the details of which will always remain far less clear than those of the southern half of the continent.

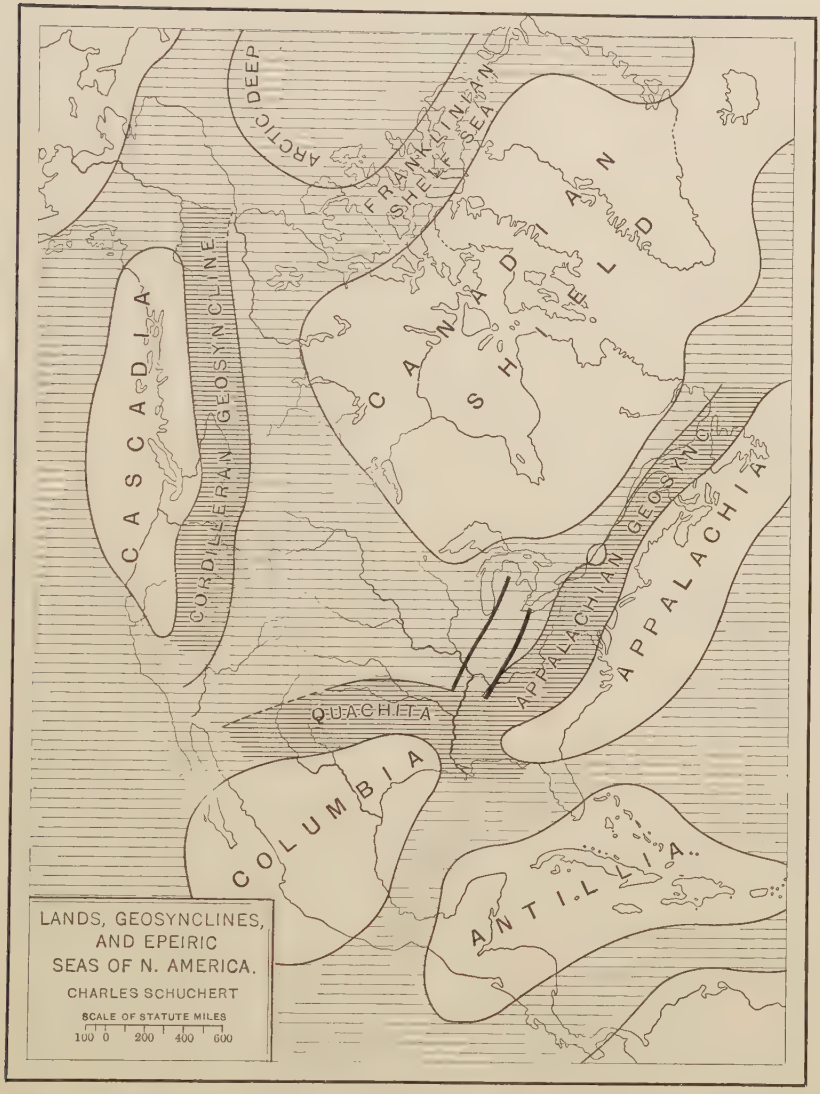


Fig. 365. — Generalized map of North America in Paleozoic time, showing in white the lands or positive elements, in darkest shading the three geosynclines or subpositive elements, and in lightest shading the extensive neutral medial area of the continent. The two heavy black lines indicate the Cincinnati and Ozark (Kankakee) uplifts.

Appalachia as here drawn is divisible into two geologic units; the northern half down to Long Island is known as Acadia, while the southern half constitutes Appalachia proper.

The surface exposures of the Paleozoic formations are shown on the Geological Map of North America at the end of this volume.

Depression Fields and Mountain Areas. — To the north, and more especially to the south and west of the shield, lie vast depression fields, or neutral and subpositive areas, which have tended through the geologic ages to lie slightly below sea-level. Because of this low level, the sea has often spread over these fields and recorded there the post-Proterozoic events.

To the east of the southern depressions occur the basal remnants of a mountain system, exposing a complex of metamorphic and igneous rocks and showing that again and again during geologic time majestic mountain ranges, studded at times with volcanoes, have been raised above the present basal structures. These mountains lay on the western side of Appalachia, the eastern shore of which has in the course of time sunk deeply into the abysses of the Atlantic Ocean (see page 357 and Figs. 282 and 365).

The western depression field is a very wide one, bordered on the west by another old land, Cascadia (see Fig. 365), which faced the Pacific. These regions were the scene of tremendous geologic activity, the struggle for dominance between the continent and the

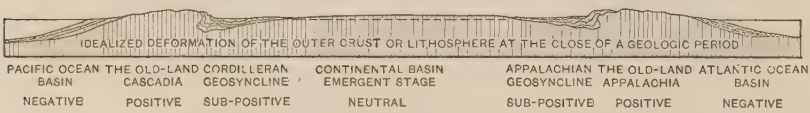


Fig. 366. — Diagrammatic cross-section through Fig. 365, at about lat. 38°, to show relation of continent to oceans at close of each period. Vertical scale greatly exaggerated. After Barrell.

Father of Oceans, in which the land was victorious, but only after building and rebuilding marginal bulwarks of chain upon chain of mountains, marked by volcanoes, from Alaska to Mexico City. The western region now embraces the grand Cordilleras.

We see, then, that North America has the form of an elongate basin, widely open at the north and nearly closed at the southeast; though in the latter place there stood for a long time a transverse mountain range, the Quachitas of Oklahoma, of which only the bases now remain, and these are in part concealed by later mantles of sediments. The geology of the Arctic shelf sea is not yet well known, but the sediments in the folded United States Mountains of Arctic America are of considerable thickness and extent. Between these elevated margins lies the great basin of North America, much of which has always been near sea-level (see Fig. 366), and over it, entering through the gaps between the marginal uplands, the oceanic waters have again and again flowed widely, to form interior shallow seas. These floods have come from the four quar-

ters, most widely from the Arctic and Pacific, least from the Atlantic, and most persistently from the American mediterranean. The partial deciphering of these multitudinous events in their orderly sequence, in addition to the similar unravellings in Eurasia by the geologists of that continent, has given the very imperfect geologic time-table presented in Chapter XX.

Paleozoic Era

Definition of Era. — We may define a geologic era as the longest division of time bounded by critical periods and characterized by comparative stability of the earth's crust and its organisms. Organic evolution was slow and pulsatory, with a tendency to specialization and adaptation among the plants and animals, during these more or less static times. The *intervals* of erosion bounding the eras were usually of long duration and the resulting unconformities are as a rule marked.

Definition of Paleozoic. — Upon the vastly thick masses of ancient igneous, sedimentary, and metamorphic rocks of Archeozoic and Proterozoic times, rest in marked unconformity the abundantly fossiliferous and as a rule little metamorphosed strata of the Paleozoic era. In the past century, geologists in general held that these rocks contained the evidences of the *first life* that appeared on the earth. Accordingly, Sedgwick in 1838 named the lower part the *Paleozoic series*, the name meaning *ancient life*, as he then believed it to contain the first life. Since then, however, as previously shown, fossils have been found in the Proterozoic, and it is now believed that low forms of life lived also in the Archeozoic. Nevertheless, the term Paleozoic is not only retained for the part defined by Sedgwick, but has been extended until it is now understood to embrace all of the time and rocks between the older Proterozoic era and the younger Mesozoic era. The Paleozoic is at present regarded as the third or fourth geologic era in the history of the earth, or the third or fourth chapter of the "book of geologic time."

Revolutions and Disturbances. — The Paleozoic is bounded below by the great Epi-Proterozoic interval, and is closed by the Appalachian Revolution (Dana), one of the most marked of the critical periods, beginning early in Pennsylvanian time and persisting during much of the Permian, when the Appalachian Mountains underwent their final upheaval. Between these two critical periods occurred other but less significant mountain-making ones, more especially toward the close of the Ordovician and Devonian,

thus dividing the Paleozoic era into Early, Middle, and Late sub-eras. The mountains then thrown up were, however, far less extensive than those at the close of the eras, and for this reason the times of their uplift are designated in this book as times of *disturbance*, to distinguish them from the times of revolutions or critical periods in the history of the earth.

Paleozoic Sub-eras. — A sub-era is a division of a geologic era. The sub-eras are bounded physically either by a revolution and a disturbance or by two disturbances, and organically by the dominance of a group or class of organisms. In the Paleozoic there are three of these sub-eras, as follows: (1) The *Early Paleozoic*, including the Cambrian and Ordovician periods, which is known as the *Age of Higher Invertebrates*, and which in a broad way may be said to be devoid of land plants and vertebrates; (2) The *Middle Paleozoic*, embracing the Silurian and Devonian periods, which is called the *Age of Fishes*, and which saw also the first land floras; (3) The *Late Paleozoic* or Carboniferous, including the Mississippian, Pennsylvanian and Permian periods, which has been termed the *Age of Amphibians* and of *Lycopods* (ancient seedless plants), and which was also the time of greatest coal-making, since then were laid down not only the best coals but the most extensive beds as well. (See geological time-table in Chapter XX.)

Division of Sub-eras. — The sub-eras are further subdivided into *periods of time* or *systems of rocks*. How this is done has already been explained in Chapter XX, but it will be well to take the matter up again in different form.

The older geologists divided the formations into systems on the basis of unconformities or marked differences in the entombed fossils. As the work proceeded and knowledge became more detailed, it grew increasingly difficult to formulate principles for the discrimination of natural periods and systems. For instance, when Murchison defined his Silurian system he divided it into an Upper Silurian and a Lower Silurian series on faunal grounds, although for a long time he was not aware of the angular unconformity between his divisions. In Bohemia, where Barrande worked a lifetime to unravel the very fossiliferous older Paleozoic, beginning in the Middle Cambrian and extending into the Middle Devonian, this geologist concluded that the entire series of strata was without "breaks," and called it all "The Silurian system," dividing it into the divisions *A* to *H*. Again, the New York State geologists of 1838–1842, in deciphering the splendid Paleozoic sequence of that state, concluded that they had throughout a conformable

series beginning in the Upper Cambrian and continuing unbroken into the Carboniferous. This sequence they called "The New York system," and separated it into five "divisions." According to more modern usage, there are here six periods, though the dividing lines of later geologists are very different from the original ones. The newer geology, however, seeks to divide the Paleozoic era in America into eleven or twelve periods.

In one form or another, geologists have always delimited their geologic divisions according to movements of the earth's crust, but how to discriminate the smaller movements from those that have more or less of a world-wide application for the delimitation of periods or systems is only now becoming clearer. Dependence will always have to be placed primarily on the fossils, but some criterion other than that of the contained life is needed to differentiate between the systems of stratified rocks. Such a physical principle apparently exists in the periodic submergences of the continents, also known as the positive changes of sea-level, for when one of the floods attains its maximum of spread, the widest distribution of similar faunas and identical species would naturally be expected. Conversely, the maximum of continental emergence must mark the absence of marine faunas in most land areas, followed for a time by more or less dissimilar faunas in all the provinces. The plotting of these periodic submergences and emergences on paleogeographic maps, not merely for one continent but for most of the world, will make it possible to define the boundaries of the systems of rocks and will also help greatly to determine a more accurate time valuation of the formations and their life in the various continents. It is, therefore, the principles of *diastrophism* and *paleogeography* that will eventually correctly define the periods or systems.

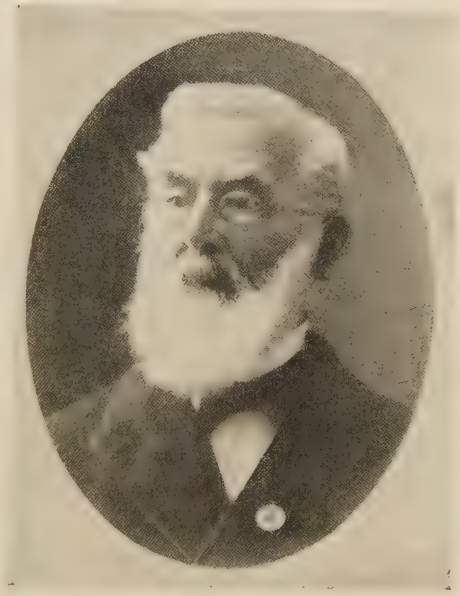


Fig. 367. — James Hall (1811-1898). Founder of the "New York system."

Definition of Period and System. — A period of time or a system of strata is a division of an era or sub-era and is bounded by breaks or intervals and loss of record other than that of erosion. The strata of each period record a marked submergence of some part of the continent and a marked emergence of the same area. The cycle of water movement may be connected with mountain making within the continent affected or elsewhere in a known or unknown continental or oceanic region. Therefore, the bounding unconformities may be of the non-conformable or disconformable type (see page 292), and when of the latter kind the organic record of the strata above and below alone may prove the delimitation.

Definition of Epoch and Series. — A period of time is very long, and a system of formations is usually of great thickness; in fact, these divisions embrace so many events that other and smaller groupings are required for their better comprehension. A period is therefore subdivided into *epochs* of time, and a system of formations is distributed into *series* of strata. In general, epochs and series are now rather arbitrary divisions established either on faunal grounds or on a long series of strata supposed to represent a sedimentary cycle, beginning in a conglomerate or sandstone and ending in calcareous deposits. While these criteria are more or less correct, they need to be checked by diastrophism and paleogeography. As a rule, however, it seems that each period has three epochs representing the early and late phases of small epeiric seas, and a middle phase of greatest periodic oceanic spreading. The epochs and series are further divided into *ages* (time) and *stages* (rocks), but these divisions have as yet no scientific precision.

Definition of Formation. — The word formation is used in different ways, and has come to be a general term embracing rocks alike or varying in character, origin, and thickness. According to Dana, it is applied to "any group in the series of stratified rocks, whether large or small, if the parts are related in period or time of origin"; as, for example, Devonian formation, or Chemung formation. He says further that "the term is also used for a group of rocks of similar constitution; as a calcareous formation, a siliceous formation." In general practice, however, formations are the smallest units that can be plotted on a geologic map, and may consist of a single more or less thick succession of like sediments, such as the Trenton limestone, Rochester shale, or Medina sandstone, or of a succession or alternation of sediments that are unlike (for example, shale, limestone, and sandstone), but have closely related faunas, such as the Hamilton formation. In short, any set of conformable strata grouped together for any stratigraphic or faunal reason or a number of reasons may be termed a formation. Where the formations are thin, as in the interior of North America, it often happens that several must be grouped together, so that

the geologist may be enabled to plot their outcrops on a geologic map. The Hunton formation of Oklahoma is a case of this kind, for it has four formations of Silurian and Devonian ages, which, in spite of their thinness, are separated by disconformities. Finally, the formations are combined into systems of rocks representing periods of time.

Old and New Divisions of the Paleozoic. — The divisions of the Paleozoic era are as follows (see also table in Chapter XX):

Sub-eras.	Recognized Periods.	Diastrophic Periods in America.
Late Paleozoic Age of Amphibians and Lycopods	Permian	Pennsylvanian
	Pennsylvanian	
	Mississippian	Tennesseian
		Waverlian
Middle Paleozoic Age of Fishes	Devonian	Devonian
	Silurian	Silurian
Early Paleozoic Age of Higher Invertebrates	Ordovician	Cincinnatian
		Champlainian
		Canadian
		Ozarkian
	Cambrian	Croixian
		Acadian
		Waucobian

Paleozoic of North America

Eastern North America. — Nowhere in the world may there be studied so complete a Paleozoic series of little deformed sedimentaries and one so replete in fossils as that of North America. For the distribution of these rocks see the geological map of North America in the pocket at the end of this book. To the north of the St. Lawrence River and the Great Lakes lies, as we have seen in Chapter XXVIII, the Canadian Shield or *nucleus of North America,*

a region composed essentially of Archeozoic and Proterozoic rocks. It was only during the early part of the Paleozoic that this nucleus was widely overflowed by the Arctic Ocean, and at no time during this era was its entire area under the sea, for nearly all of the shield east of Hudson Bay and south of Hudson Strait, that is, Ungava and Labrador, apparently has remained land at least since the close of the Proterozoic. It is around and in part over this ancient nucleus that the later Paleozoic sediments have been deposited, and in a general way it may be said that younger and younger strata are seen at the surface as one proceeds from the nucleus to the south and west and northward toward the Arctic Ocean. This statement, however, must not be taken too literally, for it will be shown that the Paleozoic sea invasions and the deposits of sediments in them were irregular in their extensions over the North American continent, and that most of these inundations lay to the south and west of the shield or *Laurentia*, as this very ancient nuclear land has been called by Dana and Williams.

Interior of North America. — Almost everywhere to the south of the St. Lawrence and Ottawa rivers and the Great Lakes, the Paleozoic strata are to be seen at the surface, extending over the wide watersheds of the Ohio, the northern half of the Mississippi and the eastern third of the Missouri rivers. The invading seas were shallow and laid down their deposits in practically horizontal and thin sheets, which even now over vast areas are not much deformed. Only in the narrow area of the Appalachian Mountains are the Paleozoic beds much folded and faulted, and here also occur the coarsest sediments and the greatest thicknesses. As one proceeds westward from this area, the folds are seen to flatten out gradually in the region of the Allegheny Mountains, and thence westward the undulations are so slight as not to be detected by the eye. However, there are also great sags here — shallow basins of rock that lie between belts of uplift. Two such basins are situated one on either side of the *Cincinnati uplift*, a low arch of strata beveled by erosion across its top, having the general trend of the Appalachians, and to be traced at the surface from Nashville, Tennessee, north of Cincinnati and then underground through the oil and gas regions of western Ohio and eastern Indiana (see Fig. 282 on page 357). It is this uplift with its nodes of older Paleozoic strata (Nashville and Cincinnati domes) that separates the eastern or Appalachian coal fields from the eastern interior coal basin of Indiana, Illinois, and western Kentucky. To the southwest of St. Louis, Missouri, lies a third extensive dome exposing older forma-

tions, the *Ozark uplift*, with another very extensive basin extending to the northwest, west, southwest, and south, and having as its youngest strata the western interior coal field (see Fig. 365).

Western North America. — This vast elevated interior country has the Paleozoic deposits covered in the south (Gulf area) and west (Great Plains country) by younger deposits, but in the far west in the folds of the Rocky Mountains the Paleozoic strata reappear at the surface. They are seen here in folded narrow bands and locally in basins from northwestern Mexico north to the Arctic Ocean, and from the Pacific states as far east as Denver, Colorado. The limited and often small outcroppings of these western Paleozoic formations are due to the repeated deformations and bevelings by erosion which they have undergone since their deposition. Further, they are so broken through and injected by igneous rocks of Mesozoic and Cenozoic age that a geologic map can show the outcrops only in a very limited way, although the Paleozoic seas had here an extension not much smaller than those of the eastern waters. Because of these inherent difficulties, the vast areas, and the scanty means of travel, the deciphering of the geologic history of the Rocky Mountains has not progressed beyond the preliminary stages. The student should, in this connection, study the geological map of North America to be found in the pocket at the end of the book.

Nature of Sediments. — The Paleozoic sediments in the Appalachian and Acadian areas are in the main a land waste, now transformed into shales and sandstones, with but little calcareous material, though limestones were laid down in Upper Cambrian and Ordovician times. In the Cordilleran sea, there was much sandstone and less shale, while the calcareous sediments were in the main of greatest thickness. Between these two bordering troughs or geosynclines of the continent the epeiric seas laid down thin sheets of sediments that, as a rule, are calcareous and include limestones, dolomites, calcareous shales and very little sandstone. In western Europe, on the contrary, the Paleozoic is characterized by the dominance of graywacke, that is, coarse detrital deposits of quartz-sand, feldspar, and mud, and by sandy slates derived from the older rocks. Because of the preponderance of the coarse deposits, the smaller seas of the European continent are believed to have lain between higher lands of ancient rocks and Paleozoic eruptives than was the case in North America, where it was only the Appalachian sea that was marked by this coarser sedimentation.

Imperfection of the Paleozoic Record. — Nowhere is there a complete record of Paleozoic formations, and even when the knowledge that has been gleaned from a study of all the North American exposures is pieced together, the record is still incomplete, though the gaps are not thought, as a rule, to represent long intervals of time. The longest array of superposed strata is to be seen in the Appalachians from northern Pennsylvania south to northern Alabama, and when the formations here are studied in detail, and widely separated places are compared with one another, it is found

Fig. 368. — Bear Grass limestone quarries, Louisville, Kentucky. The Devonian coral reef rests disconformably (at black line) on the Silurian coral reef.

that certain formations of one section may be greatly thickened or thinned or even completely absent in another (see Figs. 368, 369). Even the famous sequence in the state of New York, the "Standard Section" with which the Paleozoic strata of America are compared and correlated, is now known to be very much interrupted by breaks or intervals of erosion.

The imperfection of the geologic column is greatest in the interior of North America and more so in the north than in the south. This imperfection is in many places very marked, since an entire period or several periods may be absent. With such great breaks in the local sections the natural assumption is that these

gaps are easily seen in the sequence of strata, but in many places the beds lie in such perfect conformity upon one another that the breaks usually are not noticeable by the eye and can be proved to exist only by the entombed fossils on each side of a given bedding plane. This by no means exceptional condition of sedimentation is due to the fact that the interior sea invasions periodically flooded the low-lying continent from different directions and in varying depths, and to the further fact that the land was not folded but only warped from time to time, causing the epeiric seas to have varying extensions and outlines. In addition, there are more or less large areas that persist as lands, and these are called positive elements because the average of their movements in respect to sea-level or the strand-line is upward. They bound the interior seas or appear in them as low

Fig. 369. — Limestone exposure at Newsom, Tennessee. At the top are black shales of the Mississippian, resting disconformably on six feet of Middle Devonian, which in turn lies disconformably on the Middle Silurian.

islands. Stratigraphers are, as a rule, now fully aware of the imperfections in the geologic record, but the rocks of two unrelated formations may rest upon each other with such apparently absolute conformability as to be completely deceptive as to the great depositional break in the section studied. For instance, in the Bear Grass quarries at Louisville, Kentucky, a face of limestone is exposed in which the absolute conformability of the beds can be traced for nearly a mile, and yet within 5 feet of vertical thickness is found a Middle Silurian coral bed overlain by another coral zone of Middle Devonian time (Fig. 368). The parting between these two zones is like that between any two limestone beds, but this

insignificant line represents a stratigraphic hiatus the equivalent of the last third of Silurian and the first third of Devonian time. Such disconformities are by no means rare, in fact are very common throughout the wide central basin area of North America (Fig. 369).

Positive Continental Elements

Laurentia and Eria. — The largest, most ancient, and most persistent positive element is, of course, the nuclear area of northeastern North America previously described as Laurentia or Canadia, which is but the western end of a once far greater continent uniting North America and Greenland with the Euro-Asiatic masses and persisting throughout the Paleozoic and for a long time afterward. This land in its entirety is often referred to by geologists as the Great North Land, but Suess, following the older usage of Dawson, prefers to call it *Eria* (see Fig. 436).

Appalachia and Acadia. — Along the eastern side of North America are situated the far less extensive but also very ancient lands known as Acadia (Schuchert) and Appalachia (Dana) (see Fig. 365). The former embraces the New England States, the Canadian Maritime Provinces, southern Quebec and Newfoundland; as thus defined the land is seen to be far more extensive than the Acadia of the early French colonists, who applied the name to Nova Scotia, New Brunswick, and the neighboring islands. During much of Paleozoic time this land was locally and irregularly in movement, and therefore its different parts were variable in mass and boundary. In other words Acadia was moved and folded repeatedly and eventually was pushed far northwest upon Laurentia by the great crust movements of the Appalachian Revolution. Acadia was also the region of much volcanic activity.

Appalachia embraces all of the United States east of the Appalachian Mountains from New Jersey to Florida, and appears to have been nearly devoid of volcanic activity since the beginning of Paleozoic time. However, as all of the ancient land has since been deeply eroded and in large part buried by younger strata, we really do not know to what extent igneous activity prevailed upon it. Moreover, how far these eastern Paleozoic lands extended into the Atlantic Ocean is unknown, but Appalachia certainly extended far beyond the edge of the present continental shelf (Fig. 365).

Cascadia (from the Cascade Mountains of Oregon and Washington). — Along the western border of North America, extending from northern Nevada and California through British Columbia

into Alaska, is an immense area with almost no Paleozoic sediments excepting along the extreme eastern and western borders. This appears to have been a positive element since the earliest Paleozoic and has furnished most of the land waste for the sediments of the Cordilleran sea situated to the east of it (Fig. 365).

Other Positive Elements. — In the southwest, most of Mexico was land throughout the Paleozoic, and this element will be referred to as *Columbia*, the land of the followers of Columbus. The greater Antilles were then united into a continental mass and as such have been called *Antillia* (Fig. 365). Among the much smaller positive elements, which were nevertheless significant as islands in the epeiric seas, the most important is the Cincinnati uplift, the northern portion of which is known as *Cincinnati Island* and the southern as *Tennessee Island*. These islands did not appear as such until Middle Ordovician time, but from the Silurian on were a marked geographic feature of the eastern inland sea. *Missouri Island*, or *Ozarkia*, the Ozark Mountains area of Missouri and Arkansas, was even more persistent than were those of the Cincinnati uplift.

Subpositive Continental Elements

Seas. — The inland or epeiric seas spread between the above defined positive elements, and as the areas of these waters were also more or less subsiding ones, they are referred to as subpositive and neutral continental elements (Fig. 366). These shallow epeiric seas may be characterized as follows: The *Central Interior sea* (Mississippian sea of authors) occupied variably at different times the drainage basin of the Mississippi River, from the Appalachian Mountains west to the eastern edge of the Great Plains and north from the Gulf of Mexico into the Hudson Bay depression. It was a Paleozoic epeiric sea and was divided into an eastern and a western part situated respectively on either side of the Cincinnati uplift. The extreme eastern part of the Central Interior sea will often be referred to as the *Appalachian trough* or geosyncline; it was the chief subsiding area of the Central Interior sea, forming a variably narrow trough immediately to the west of Appalachia proper and extending from eastern New York into Alabama (see Fig. 365), where its deposits pass beneath subsequent rocks. More than 30,000 feet of sediments were laid down in this geosyncline in eastern Pennsylvania, with smaller thicknesses to the north and south. The life of this sea was chiefly derived from the south or Gulf of Mexico and secondarily from the northeast or Gulf of St. Lawrence, but at

times also from the Pacific and Arctic. Another trough lay in the south and is known as the Quachita geosyncline. The *Cordilleran sea* occupied the area of the Rocky Mountain geosyncline and the Great Plains, and at times extended from Mexico into the Arctic Ocean. It was often in connection with the Central Interior sea, but its life came in the main from the Pacific and less often from the Arctic.

In the preceding paragraphs some of the positive and subpositive continental elements have been defined. Both are parts of the emerging continents, while the negative elements are the subsiding oceanic areas. It should, however, be understood that while the sum total of the continental movements in relation to the water level is upward, and in the same way the average of the oceanic bottoms is downward, nevertheless parts of the continents have gone permanently under the ocean, while parts of the oceanic areas have been added to the continents. This is explained in more detail in Chapter XXI.

CHAPTER XXXI

CAMBRIAN TIME AND THE DOMINANCE OF THE TRILOBITES

Cambrian in General

Origin of the Term Cambrian. — The Cambrian period of time or system of rocks takes its name from Cambria, the Roman name of northern Wales, where the deposits were first studied by Professor Sedgwick of Cambridge University in 1833. The term, however, was intended to apply to what is now called the Ordovician period, the one following the Cambrian, and although Sedgwick often objected to the transposition, brought about in the main by his friend Sir Roderick Impey Murchison, this misapplied usage has unfortunately persisted. On the other hand, it now appears that the formations heretofore embraced under the term Cambrian are not of a single period, but may be grouped into three periods, and for this reason the terminology is not yet finally established. To keep this matter clearly before the student, the accepted classification is retained for convenience, while the new arrangement is presented in the form of three *series* of formations, — Lower Cambrian or Waucobian time, Middle Cambrian or Acadian time, and Upper Cambrian or Croixian time.

Marked Unconformity at the Base of the Paleozoic. — In most places where the Cambrian or any later portion of the Paleozoic sedimentaries rests on the older Proterozoic or Archeozoic rocks, a marked unconformity is seen to be present between the strata. This unconformity is more pronounced and of wider extent than any subsequent one, though there are some localities, for instance, in western Montana and southern British Columbia, where the Paleozoic strata rest without marked unconformity (disconformity) on the earlier formations of Proterozoic time.

Cambrian Life. — The Cambrian period is the first one in the Paleozoic era. It is also the first one in the history of the earth with an abundance of life preserved as fossils. This animal life, which consists entirely of invertebrates, contains representatives of all of the more fundamental types, ranging from simple sponges to complex forms of Crustacea. The common animals are almost wholly trilobites (crab-like animals fully described in the next

chapter) and brachiopods (bivalved animals described in Chapter XXXIII), and as the former are characteristic of the Cambrian we speak of them as the dominant animals. See Pls. 1 and 2.

In the Lower and Middle Cambrian the external skeletons of animals were commonly made up of a substance containing some nitrogen (chitin and phosphate of lime), but subsequently thick-shelled molluscs and brachiopods with shells composed of carbonate of lime appeared in ever greater quantity and variety. It is estimated that about five hundred species of Cambrian invertebrate animals have been described from North America alone. From all countries together there are known fully one thousand species, about two thirds of which are trilobites and brachiopods.

Absence of all Land Plants. — Not the slightest evidence of a positive kind exists showing the presence of a land flora in Cambrian time, and the same statement is applicable to the greater part of the succeeding Ordovician. When, however, we consider that only the lower types of land plants could then have existed and that these were soft and nearly devoid of woody material, the only preservable portion, there is nothing extraordinary in this extreme imperfection of the plant record. The bottom-living plants of the sea, the *seaweeds*, are also very perishable and few of them are known as fossils; even in sediments of the finest sort, where one might expect to find them, they are very rarely preserved, and then only as impressions. Therefore, land plants do not occur in the geologic record until the woody ones appeared, and none of these latter are known earlier than late Ordovician time.

Cambrian Climates. — From the very wide distribution of the reef-making corals in Lower Cambrian times, as stated on a subsequent page, it is evident that the waters were warm and equable over most of the earth, since these animals lived not only in the present temperate regions but also in both polar areas. The wide occurrence of limestone-depositing seas in Middle Cambrian time, and more especially in the Upper Cambrian, with an abundance of varied life, is further evidence of mild climates all over the world probably throughout Cambrian time.

Significance of Cambrian Seas. — From the paleogeographic maps (Pl. 3) and the description of the Cambrian seas it will be seen that all of these waters and their stratified rocks lay upon the continent of North America between the bordering lands from which the sediments came. In other words, they were epeiric seas, and not marginal overfloodings of the continental shelves by the oceans (shelf seas), as is the case with the present Atlantic and Pacific

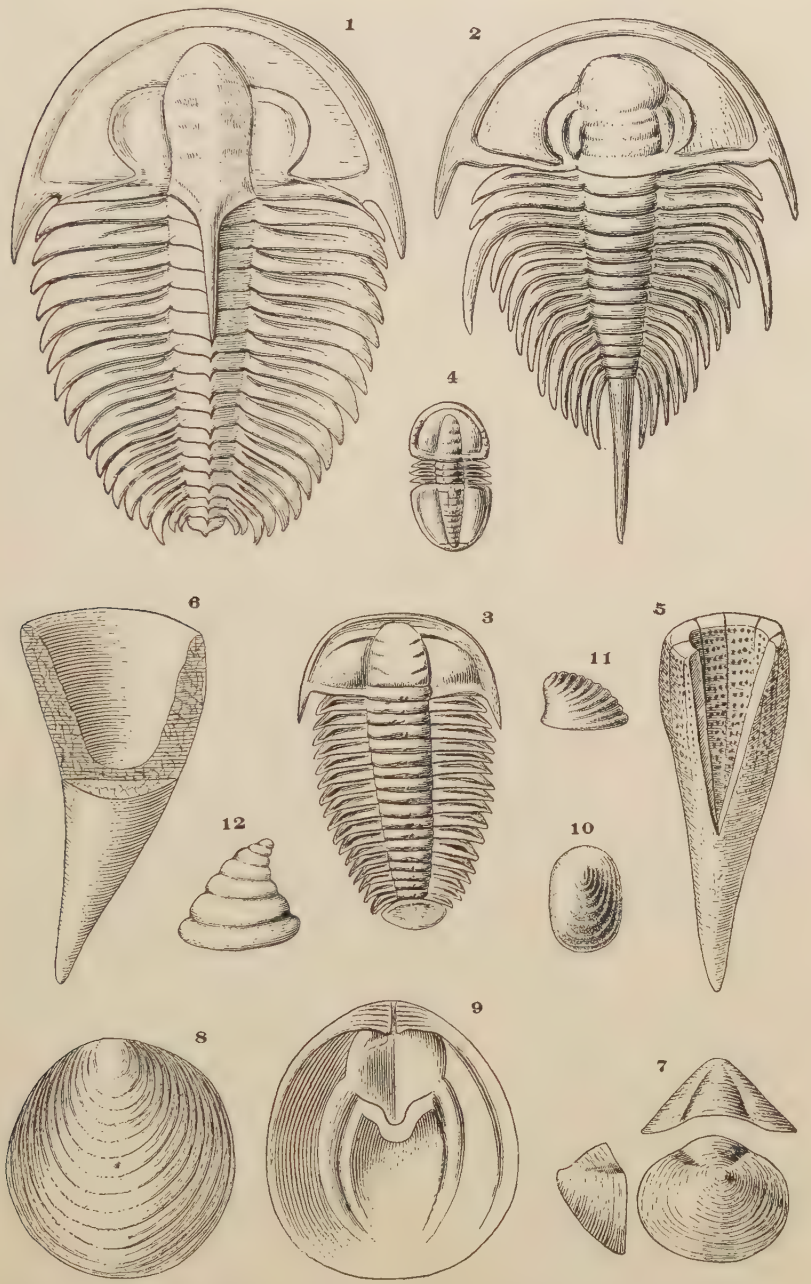


Plate 1. — Lower Cambrian trilobites (Figs. 1–4), gastropods (10–12), brachiopods (7–9), and corals (5, 6). See Appendix B.

oceans. If the present oceans are more than full and hence overflow more or less extensively the continental shelves, then the oceans of Cambrian time were in a far greater flood condition. The continents at present stand higher above the oceanic strand-line than was the rule in geologic history, and throughout Paleozoic time North America stood considerably lower relatively to this line, possibly 200 to 300 feet throughout the Mississippi drainage area. That the oceanic level is not a constant one is well attested by geologic history, but that it has been in ebb and flow to such an extent as is shown in the paleogeographic maps presented in this book has only become clear during the past few years.

Leading Cambrian Workers. — Our first accurate knowledge of Cambrian life was obtained in Bohemia through the great industry of a Frenchman, Joachim Barrande, who spent the greater part of his life as an exile at Prague. The complete stratigraphic succession of this period was first determined by the splendid work of Swedish geologists, while the American succession and faunas have been developed almost entirely by Walcott.

Lower Cambrian or Waucobian Time

The Lower Cambrian was made known by Walcott many years ago, but it was only in 1912 that he proposed the term Waucobian for these rocks, taking the name from Waucoba Springs, Inyo County, California, where the system has a thickness of not less than 5670 feet.

Waucobian Seas. — The paleogeographic maps of the probable seaways of Cambrian time are shown on Pl. 3. From them it is seen that the Pacific Ocean in earliest Lower Cambrian time first invaded the land in the Great Basin area and gradually spread northward, forming throughout the Cordilleran geosyncline a sea which finally united with the Arctic Ocean. Some time after the appearance of the western Cordilleran sea, a similar waterway developed to the west of Acadia and Appalachia, finally extending as a narrow trough — the Appalachian geosyncline — from Alabama to southeastern Labrador. At its maximum this inundation did not submerge more than 18 per cent of North America. It is not known where these waterways intercommunicated, but the entombed life of their deposits makes it clear that they had such a connection, for some of the species are common to these two widely separated seas, and, what is more important, the faunas of both regions have a general likeness. This is true not only for North America, but also for the whole northern hemisphere, indicating that the oceans were then openly connected with

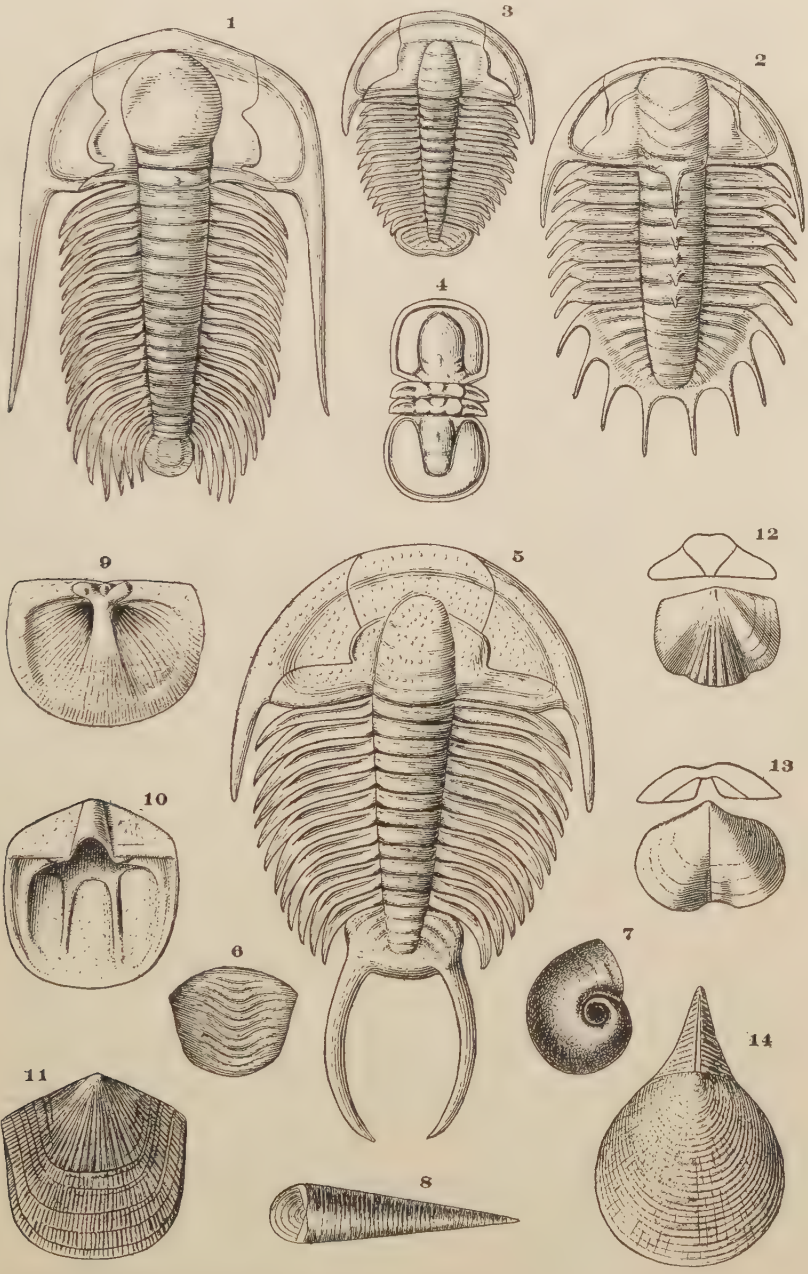


Plate 2. — Middle and Upper Cambrian trilobites (1–5), gastropods (6, 7), pteropod (8), and brachiopods (9–14). See Appendix B.

one another. It is therefore said that the life of the Lower Cambrian was *cosmopolitan* in character because the same, or nearly the same, kinds of fossils occur in all the known areas.

Waucobian Formations. — In the Cordilleran sea the Lower Cambrian had by far the best development. Here Walcott has measured sections of strata ranging from 1500 to 5670 feet in thickness. The material is usually sandstones or quartzites and was almost all derived from Cascadia, the bordering land on the west.

In the Appalachian trough and sea the Lower Cambrian thicknesses in places are also very great. In Vermont and northeastern New York there appear to be about 5000 feet, mainly of slate and sandstone, with an additional 1000 feet of limestone at the base. This material was very largely derived from Acadia and but little from Laurentia, which had remained a low flat land since its peneplanation in Proterozoic time. In eastern Pennsylvania, western Maryland and Virginia there are 1000 feet of limestone at the top with 4700 feet of sandstone and snale. A very similar thickness occurs in Tennessee, Georgia, and Alabama. All of the coarse materials came from Appalachia.

First Abundance of Fossils. — The life of the Lower Cambrian is particularly interesting because it is the first or oldest life of which we have a good knowledge, and its leading features must therefore be described. In the oldest of these deposits in California and Nevada, fossils are scarce and all that have been found are two forms of trilobites. Near the top of the Lower Cambrian, fossils are, however, abundant and consist of trilobites, snail shells, brachiopods, and very primitive stony corals (*Archæocyathidæ*), which also remind one of certain sponges (Pl. 1). In Inyo County, California, occur limestone reefs made up of such corals, the oldest ones known. These fossils occur in many parts of the world: Labrador, with reef limestones up to 50 feet thick; New Siberia, in 70° north latitude; Sardinia; Spain; Australia, with limestones fully 200 feet thick; and finally in Antarctica, as reported by Shackleton. (For further remarks, see Chapter XXXV.) The trilobites were the most characteristic animals of the Lower Cambrian. Nearly all of the brachiopods of this period had shells made of phosphate of lime, while those of the Upper Cambrian and later periods were of carbonate of lime. The gastropods (shells like the snails, drills, and periwinkles) were rare and of the most primitive type; with one exception, they were hood-shaped and not spirally coiled as is usually the case among these animals (Pl. 1, Figs. 10–12). The conical three-sided tubes known as *Hyolithes* were abundant (Pl. 2, Fig. 8). There were still other types of animals, but no bivalved molluscs (mussels) or cephalopod (nautilids).

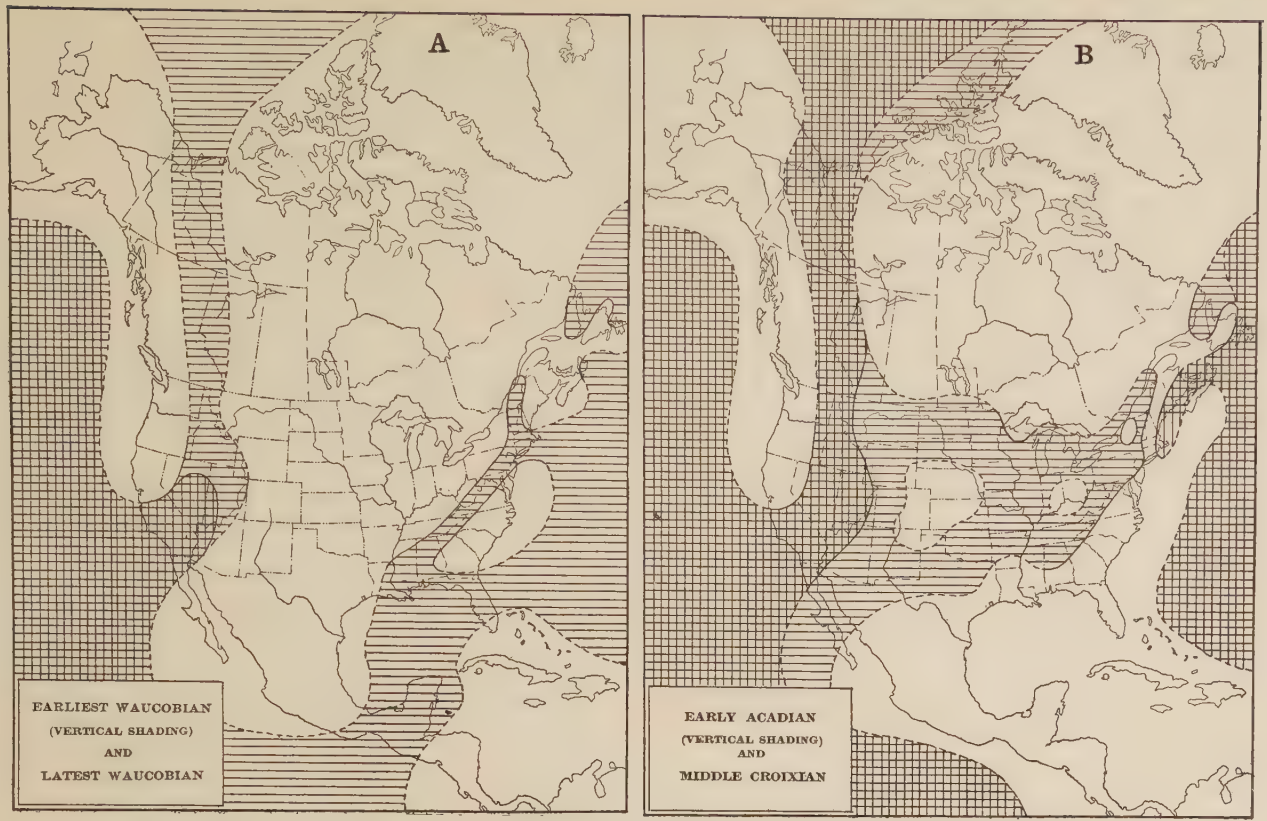


Plate 3. — Lower (A), and Middle and Upper (B) Cambrian paleogeography.

Characteristic Fossils of the Waucobian. — The Lower Cambrian in America is divisible into four faunal zones. The oldest one — Nevadia zone — is restricted to the Cordilleran trough, but the other three – Elliptocephala zone, Callavia zone, Olenellus zone — are common to this and the Appalachian trough.

The more characteristic fossils are as follows: of trilobites, *Olenellus*, *Mesonacis*, *Elliptocephala*, *Callavia*, *Nevadia*, *Atops*, and *Eodiscus;* among the gastropods, *Stenotheca* and *Scenella;* among the brachiopods, *Paterina*, *Kutorgina*, *Mickwitzia*, and *Obolella;* and of the corals, the Archæocyathidæ.

Significance of Lower Cambrian Life. — As trilobites, which belong to the highest division of invertebrate animals and are therefore really complex organisms, were the dominant life of the Lower Cambrian, it is plain that life could not have originated in this time. Even though it is now established that a variety of animals was present in the Proterozoic, still the change in the life of the Lower Cambrian, as compared with that of the former epoch, is very remarkable. We have seen that in the Proterozoic there were almost no organisms other than lime-secreting seaweeds and worm tubes, yet in the Lower Cambrian there was an abundance of very varied and highly complex animals. These facts mean that there is a very great loss of record in the geologic column between the latest Proterozoic and the oldest Cambrian deposits, the further significance of which has been discussed in the preceding chapter (page 569).

Green Mountains Disturbance. — Toward the close of the Lower Cambrian, both the Cordilleran and Appalachian geosynclines appear to have been drained of all or most of their marine waters, and a long time ensued before another cycle of marine invasion took place. In the meantime, life was evolving on the continental shelves, areas not now accessible to us for geologic study, and when the floods reappeared in the geosynclines they spread faunas that were unlike the previous one. This record of organic change during the interval of sea withdrawal is missing everywhere between the youngest Lower Cambrian and the oldest Middle Cambrian deposits, no transition faunas being yet known. Stratigraphers are now taking advantage of facts of this kind as a basis for distinguishing the periods one from another, and thus classifying them, as previously discussed.

This absence of epeiric seas in the Appalachian and Cordilleran troughs means that either one or more of the outer ocean basins had been deepened, thus withdrawing their waters from the geosynclines. Further, Walcott has shown that at the close of Lower Cambrian time the lands to the east of the Appalachian geosyn-

cline were elevated into a low ridge or barrier, which apparently extended from Newfoundland certainly to Connecticut and possibly into Alabama. It was this ridge that prevented the western or Pacific waters of the Cordilleran sea during Upper Cambrian time from mixing their faunas with those of the northern Atlantic Ocean (Poseidon), which lay to the east of the ridge or land. For easy reference the movement which brought about this uplift may be known as the *Green Mountains Disturbance*, since the Green Mountains of Vermont are now situated on the western border of the elevated area.

Middle Cambrian or Acadian Time

The sequence of the strata of this period and the faunas contained therein were first developed by G. F. Matthew from the region about St. John, New Brunswick, a part of the Acadian country, hence the name Acadian, proposed by James D. Dana in 1874. During Middle Cambrian time the Cordilleran sea had about the same limited geographic extent as that of the Lower Cambrian, while the Appalachian geosyncline appears to have remained continuously above sea-level.

Sediments. — In the Cordilleran sea the sediments of Middle Cambrian time were essentially thick- and thin-bedded limestones with but little shale. The thicknesses vary between 3000 feet in Nevada and 8300 feet in the Robson district of Alberta, Canada. In the Grand Canyon of the Colorado there are less than 1200 feet of sandstones and shales (see Pl. 3, Fig. B).

Acadian Faunas of the Cordilleran Sea. — The life of the Cordilleran sea was distinctly of the Pacific realm, very similar faunas being known in China. Trilobites were still dominant, and there was a greater variety of these interesting animals (Pl. 2, Figs. 2–4) than in the preceding epoch. The brachiopods were far more numerous, but still small, and almost all of them not only had phosphatic shells but were very similar to those of the Lower Cambrian.

The fauna of the Cordilleran trough is marked by the trilobites *Olenoides*, *Dorypyge*, *Neolenus*, *Ogygopsis*, *Asaphiscus*, *Bathyuriscus*, and *Agnostus*, and by the brachiopods *Micromitra*, *Acrothele*, and *Nisusia*. A very extraordinary and varied fauna represented by over ninety genera has been described by Walcott from the black Burgess shale found on Mt. Stephen in British Columbia, where this zone is but a few feet in thickness. The fossils are essentially crustaceans, with phyllopods, worms and sponges prominent. Other forms are medusæ (jelly-fish), pelagic and bottom-living holothurians, brachiopods, and Hyolithes with pteropod-like wings (see Pl. 2, Fig. 8). The finding of this fauna has re-

vealed a host of unsuspected animals, and furnished a good illustration of the great variety of life that lived in these early times; it is a revelation of how very imperfect our knowledge must be of any geologic age.

Acadian Faunas of the Atlantic Area. — In the Acadian region and in Newfoundland, there are other Middle Cambrian deposits, here essentially muds and sands, with distinctly different fossils, though of the same general faunal development as those of western Europe, in other words, of the Atlantic province (Pl. 2, Fig. 1). Hence the world no longer had a cosmopolitan fauna, but there were at least two distinct evolutionary areas whose respective dispersal centers were the Pacific and Atlantic oceans.

Close of the Middle Cambrian. — In all places where the Upper Cambrian strata repose on those of Middle Cambrian time it is seen that the life of the one series is sharply distinguished from that of the other; in other words, there are no known transition faunas of this time in America preserving the stages of evolving forms, and this is thought to indicate a break in deposition and an absence of faunal record. Only in the Cordilleran trough is there a possibility that the transition faunas may be recovered, for as yet we know little of its geology; in the Appalachian geosyncline the Upper Cambrian rests on the Lower Cambrian with all of the Middle Cambrian absent. This is evidence that in the latter region the elevation brought about by the Green Mountains Disturbance had not yet been overcome by erosion. However, there are so far no data showing that either Appalachia or Cascadia had been further elevated at the close of Middle Cambrian time. The subtraction of the oceanic waters at this time appears to have been due to crustal movements elsewhere than in North America, probably in the deep ocean basins, as previously suggested.

Upper Cambrian or Croixian Time

In Upper Cambrian or Croixian time (from the St. Croix River of Wisconsin, where these strata are well developed and fossiliferous), the seaways not only reoccupied the Cordilleran and Appalachian troughs, but the waters for the first time in the Paleozoic spread widely over the continent, occupying much of what is now the Mississippi basin. When the flood was at its widest, it covered more than 31 per cent of North America (Pl. 3, Fig. B). In general, the deposits are limestones, dolomites, and calcareous shales, with the minimum amount of sandstones.

Sediments. — In the northern part of the Central Interior sea the deposits are mostly sandstones, with a thickness in Wisconsin of about 720 feet. They are the residual materials or the loose rock and soil (regolith) of a long period of erosion and have been brought from Laurentia and the Adirondacks. These sands in small amount reached as far as the Ozark region of southern Missouri, where the Upper Cambrian deposits are thin and consist mainly of limestone and dolomite. On the other hand, in the Arbuckle Mountains of Oklahoma there are no less than 3000 feet of pure limestones and dolomites.

The Appalachian trough is another area of thick sediments of this age, nearly all of which consist of magnesian limestones with some shale. In Alabama the thickness is about 4000 feet, and this depth remains fairly constant all the way north to Chambersburg and Mercersburg, Pennsylvania.

The deposits in the Cordilleran trough are also essentially calcareous, with an average thickness of over 3000 feet.

Establishment of the Lime-secreting Habit. — The epeiric seas of Middle and Upper Cambrian time deposited a very great amount of rocks consisting of carbonate of lime; this means not only that the waters were clean of muds but that their temperature was warm as well. Life was more prolific in the Upper Cambrian and there was also an abundance of invertebrate animals with lime carbonate skeletons. In other words, for the first time in the history of the earth there was an abundant molluscan fauna, and the greater abundance of carbonate of lime in the seas established the lime-secreting habit permanently in many classes of animals. The trilobites, although less varied than before, were still abundant (Pl. 2, Fig. 5), while the brachiopods with phosphate of lime shells were now at the height of their development, and those forms having valves of carbonate of lime (Pl. 2, Figs. 9–13) were rapidly increasing. Then there were also a number of coiled and spiral gastropods (Pl. 2, Figs. 6, 7), and a few cephalopods of the pearly nautilus type as well.

Characteristic Fossils of the Croixian. — The more characteristic trilobites of the Central Interior sea and of the Cordilleran trough were *Dikellocephalus*, *Saukia*, *Illænurus*, *Conaspis*, and *Crepicephalus*. The earliest limulid (horseshoe crab) is present in *Aglaspis* and a eurypterid in *Strabops*. Of brachiopods there were *Linnarssonella*, *Lingulepis*, *Obolus*, *Syntrophia*, and *Billingsella;* of gastropods, *Owenella*, *Holopea*, and *Pleurotomaria*-like forms.

Close of the Upper Cambrian. — At present it is impossible to define the closing events of the Cambrian because of a difference of opinion among paleontologists as to the age of the formations usually accepted as the last members of the Upper Cambrian. The matter is set forth below. In any event, there was no mountain making at this time in North America. Apparently the closing

epoch of the Upper Cambrian was a time of quiet emergence and withdrawal of the sea.

Ozarkian

In 1911, Ulrich proposed the name "Ozarkian system" for a series of formations that had been referred mainly to the Cambrian and in part to the Ordovician. His definition of the new system includes all the formations in the Appalachian valley that can be shown to be younger than the top of the Upper Cambrian Nolichucky shale in eastern Tennessee and older than the base of the Beekmantown limestone as developed in southern and central Pennsylvania. The name is taken from the Ozark uplift in southern Missouri where the Ozarkian begins with a massive limestone known as the Potosi dolomite. The upper limit there included two Missouri formations, the Roubidoux and Jefferson City, which he subsequently referred to the Canadian period of the Ordovician.

At present, then, Ulrich begins the Ozarkian in Missouri, as in 1911, with the Potosi, but now closes it with the Gasconade. In the Adirondack area of New York, the Potsdam, Hoyt (Theresa), and the greater part of the Little Falls are regarded as of early Ozarkian time, but until Ulrich's evidence is fully presented, Walcott (1914) thinks it well to leave the two lower formations (= Saratogan) in the Upper Cambrian. In the upper Mississippi valley, Ulrich and Walcott both include the Mendota, Madison, and Oneota in the Ozarkian. In the southern Appalachian area, Ulrich refers the Nolichucky to the Cambrian, and begins the Ozarkian, as in 1911, with the Briarfield and Ketona, continuing upward into the Copper Ridge, and closing with the Chepultepec. In Pennsylvania, the Ozarkian is represented by thick formations of limestone, dolomite, and sandstone comprised in the Kittatinny, Conococheague, and corresponding formations.

Ozarkian strata are best developed in the southern Appalachians, with more than 4000 feet of dolomite in eastern Tennessee and 2500 feet of still older magnesian limestones in central Alabama. The total thickness may even attain 9000 feet.

The early Ozarkian sea invaded the Mississippi valley as far north as southern Wisconsin, spreading at the same time into the southern extremity of the Appalachian valley. The Atlantic also invaded the middle Appalachian valley about this time. Middle and later Ozarkian seas seem to have come in exclusively from the south, persisting a long time in the southern Appalachian and Ozark areas and spreading finally into Pennsylvania and New

York in the east, and through the upper Mississippi valley in the west.

As a rule, fossils are scarce throughout the Ozarkian, although locally they may abound in undescribed species. The most prevalent ones in a fauna of about two hundred forms are several species of calcareous seaweeds (*Cryptozoön*). A few brachiopods and more trilobites, most of them closely allied to Upper Cambrian species, are commonly associated with numerous gastropods and cephalopods having decided Ordovician affinities.

CHAPTER XXXII

TRILOBITES

History. — Trilobites were the first fossils to attract the attention of naturalists and have long been of popular interest. It was Lhywd, the curator of the Ashmolean Museum at Oxford, England, who, in 1698, first called attention to an entire specimen. He did not know how to classify it but thought it was the skeleton of an unknown fish, and for a long time the animals were regarded as beetle wings, caterpillars, insects without wings, fossil butterflies, and even molluscs. The great Swedish naturalist, Linnæus, first correctly recognized their relationship with the Crustacea, animals such as shrimps, crabs, and lobsters. Professor Walch of Jena, Germany, in 1771, gave them the generic name *Trilobites*, a term that has since been raised to the rank of a subclass *Trilobita* of the class Crustacea of the phylum Arthropoda, which contains an exceedingly varied array of animals with articulate or segmented bodies and limbs, among them the crustaceans, insects, scorpions and spiders. There are now about two thousand kinds of trilobites known (see Pls. 1, 2, 6, 9, 18).

Definition. — The word trilobite means *three-lobe-like*, and has reference to the three longitudinal lobes (the central *axis* and lateral *pleura*) seen on the dorsal or upper side of most trilobites (see Fig. 370). They were sexed animals. Their bodies were made up of segments, many of which articulated upon one another; and these segments were gathered together into three divisions, as may be seen in any entire specimen of the upper shell or *carapace*, the part usually preserved. The under, or ventral, side with the limbs had a very thin outer shell and was preserved only in exceptional conditions, usually in black, more or less sulphurous shales. The carapace was thin, and made up of chitin (very much as in horn, hair, etc.), a nitrogenous substance to which is added more or less of lime salts. Chitin greatly resists chemical alteration, and this is the reason why trilobites are so often preserved as fossils.

Habitat. — Trilobites inhabited only marine, and in the main, shallow, waters, and their tests or outer shells are found in all

kinds of marine sediments, but chiefly in shales and limestones. Most of them were good swimmers, some crawled over the bottom, while others lived partly buried in the muds. They were *characteristic of the Paleozoic era,* beginning in great variety in the Lower Cambrian and dominating the seas of Cambrian (55 genera and 300 species) and Ordovician time (80 + 950). In the Silurian, though they were still common, the trilobites were nevertheless on the decline (30 + 485), and this ebbing of their vital force is seemingly shown in many picturesque forms replete with protuberances, spines, and exaggeration of parts. As a rule, in evolution, one finds that when an organic stock is losing its vital force there arises in it an exaggeration of parts, as if heroic efforts were being made to maintain the race. Spinosity in animals is often the prophecy of tribal death. In the Devonian, the variety and number of the trilobites were greatly reduced (20 + 105), at a time when the ancient types of fishes, who undoubtedly fed on these crustaceans, began to be common in the seas. In the later Paleozoic seas, the trilobites were relics, or animals surviving from a time better suited to their needs, and one by one they vanished, until a little before the close of the Paleozoic era none were left. While they were in their prime, they dominated the life of the seas, since they were the chief carnivores and scavengers of Cambrian and Ordovician times, but with the rise of the fish-like animals in the Silurian and the true fishes in the Devonian their death knell was sounded by the incoming greater mentality and alertness of the vertebrates.

Habits. — Most trilobites could roll their bodies up like the sow-bugs or pill-bugs of our cellars, animals that are not insects but Crustacea (Isopods) and distant relatives of the trilobites. This rolling up was for the protection of the softer and more delicate parts of the ventral side, thus presenting to the enemy the hard, thick carapace, an effectual armor against other trilobites but ineffective against the fishes. The power of coiling up first appeared in the Upper Cambrian, and with the Ordovician all forms had adopted such a method of protection.

Size. — In size, the trilobites varied greatly at maturity, ranging in length from 0.38 of an inch up to 27.5 inches, but an average size was about 1.5 inches. Many species attained a length of from 3 to 4 and even 6 inches, but these were large individuals, and those above a foot in length were giants. Those represented as from 18 to 27.5 inches are, in nearly all cases, based on restorations pieced together from large fragments.

Large species appeared at different times and in every case seemed to occur near the zenith of the evolution of the stocks to which they belonged. With the sharp decline of the trilobites in the Devonian, no large forms are seen after Upper Devonian time.

The oldest giant forms lived in the Middle Cambrian, species of *Paradoxides* found in New Brunswick, Massachusetts, and Bohemia ranging from 12 to 14.5 inches (*P. regina*) and even to nearly 18 inches (*P. harlani*, Pl. 2, Fig. 1). In the Middle and Upper Ordovician there were many large trilobites; several were nearly 16 inches long (*Megalaspis gigas*, *M. heros*, *Asaphus barrandei*), and one form even reached a length of 21 inches (*Isotelus gigas*). The largest of all trilobites occurs in the Ordovician rocks of France and Portugal and is 27.5 inches in length (*Uralichas ribeiroi*). In the Silurian, there were many large forms but no giants. In the Lower Devonian, at least two giants, nearly 16 inches long, occurred (*Homalonotus major*, *H. armatus*), and in the Middle Devonian lived the last giant species (*Dalmanites*, 11 and 16 inches; *Calymene*, 8 inches; and *Terataspis*, from 18.5 to 24 inches). "With his extravagant armor of defense and aggression, *Terataspis grandis* must have been easy lord of his invertebrate domain and no very palatable morsel for the heavily plated fishes of his day" (Clarke).

Definition of Parts (study with Fig. 370). — The carapace of trilobites is divided transversely into (1) a head portion, called the *cephalon;* (2) a series of segments, forming the *thorax;* and (3) a tail-piece or *pygidium*, forming the abdomen. The *axis* is the area of the vital organs, while the *pleural regions* are protective coverings over the ventral limbs.

The cephalon is composed medially of the *glabella* and the outer *free cheeks* bearing the *compound eyes*. In many forms the free cheeks are separated from the glabella by a *facial suture* which generally shows as a faint raised line, and in all such forms the three parts are apt to separate after death and thus cause imperfect fossils. In some trilobites compound eyes are not known, such forms being called blind; usually, however, two more or less large compound eyes are present. In the majority of trilobites each compound eye is covered over by a single cornea and the individual lenses beneath may or may not show through. In others each lens has its own cornea. The number of lenses in a compound eye may vary from fourteen to the astonishing number of fifteen thousand. Imagine an animal with thirty thousand eyes!

The thorax consists of a variable number of articulating segments, the number being constant in the adults of each species, but variable in the young of each form and in the genera. There are never less than two, as in *Agnostus* (Pl. 2, Fig. 4), or more than twenty-nine. In a general way, it may be said that where there are many thoracic segments the pygidium is small, and where there are few the abdomen is large.

The pygidium or abdomen of trilobites may be small or large, and consists of a single piece of united segments varying between two and twenty-eight in number. Generally, the axial and pleural regions are plainly demarcated and some forms clearly show the number of coalesced segments.

Ventral Side. — Beneath the glabella and hinged to its bent-over and thickened posterior margin is the *hypostoma* or upper lip cov-

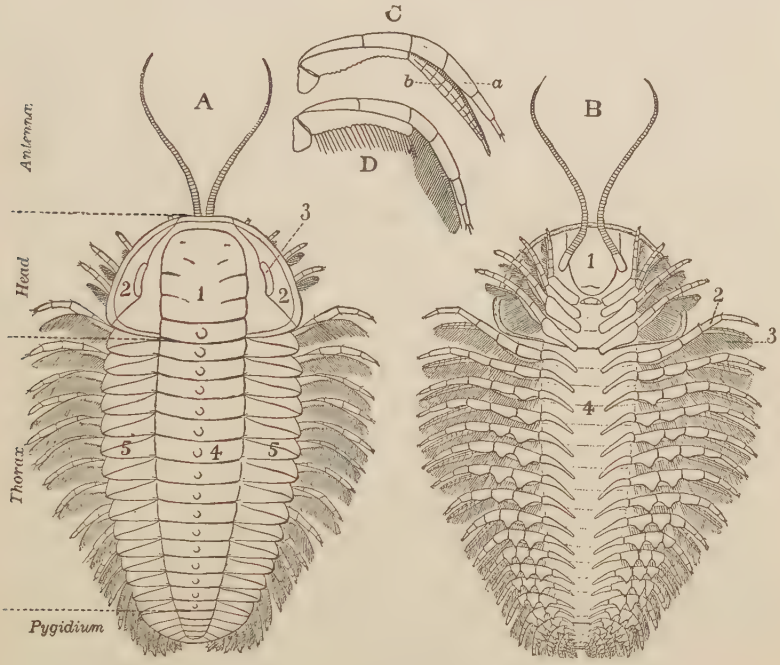


Fig. 370. — Sketches of a complete trilobite (*Triarthrus becki*). × 2. After Beecher. *A*, dorsal or upper side of carapace, showing three lobes, pleura (5), rachis or axis (4), glabella (1), and free cheeks (2) which bear the eyes (3). *B*, ventral or under side, showing biramous limbs (2, 3) attached to rachis, and upper lip or hypostoma (1) which covers mouth. *C*, one of the double legs stripped of setæ or breathing organs. *D*, another leg with setæ attached; the upper member of the leg is for breathing and swimming and the lower part for crawling.

ering the mouth (Fig. 370 *B*). On each side of this plate there may be a pair of short or long antennæ, or many-jointed sensory or feeling organs. Otherwise, all the limbs are in pairs, and each limb is double, or biramous, with each of the two branches, in turn, made up of many joints.

The head has four pairs of such biramous limbs which serve also for chewing the food and passing it into the mouth. Back of the head each thoracic and abdominal segment has its similar pair of biramous limbs. Both limb

branches arise from a single basal joint fastened to the axis; one stouter ramus or leg branch with fewer joints serves for crawling, while the other, which is more delicate and much more jointed, serves for swimming and is also replete with long hair-like appendages that are delicate tubes in which the circulating blood extracts from the water the necessary oxygen for life sustenance (Fig. 370 *D*).

Trilobite Moulting. — As trilobites grow, they periodically shed their chitinous shell, as do the crabs, and this happens many times before they attain full growth and probably occasionally during maturity. During the time of moulting the animals grow and the detailed characteristics are changed, along with the introduction of new segments. At first, the trilobite is a very minute, apparently unsegmented animal, all head (Pl. 6, Figs. 14, 15); then it consists of head and pygidium, the latter of which rapidly adds more segments; these stages are followed by other moults that long before maturity is attained rapidly introduce the full number of thoracic and pygidial segments according to the characteristics of each species. Later moultings simply enlarge the individuals.

Evolution. — Trilobites are the most primitive of Crustacea and appear to have arisen out of crawling worms, or, more probably, annelids, in Proterozoic time. In the Lower Cambrian many of the trilobites were primitive and betray their annelidian ancestors in their abundant and variably segmented thorax and very small tail. In pre-Cambrian time the annelidian stock from which came the trilobites also gave rise to the sea-scorpions or eurypterids (Pl. 12), and, along a third line of evolving forms, to the horseshoe crabs or limulids. Out of the eurypterids in the Middle Silurian came the scorpions and through these the entire class of arachnidian (spider-like) animals, such as scorpions, spiders, and mites. It is thought that out of some Silurian or Devonian trilobite that habituated itself to the land-waters and became amphibious was derived the stem stock of insects. The Crustacea have probably also developed out of trilobites which gave rise to the stock Phyllopoda in pre-Cambrian times, these latter in turn giving rise to the degenerate Ostracoda or bivalved Crustacea in the late Cambrian and to the Cirripedia or barnacles in the Ordovician. Another line of Crustacea arose in the Phyllocarida in the Lower Cambrian or earlier, and out of these probably came all of the remaining Malacostraca.

CHAPTER XXXIII

SHELLED ANIMALS

Shelled animals constitute the bulk of the fossils that the student of extinct invertebrates meets with in the sedimentary rocks. They are exceedingly varied, but in this book only those stocks will be studied that have especial significance in Historical Geology. The older naturalists also included among the Mollusca — the true shell-fish such as clams, oysters, conchs, etc. — the class Brachiopoda, and they are here considered with them, but this is done only for convenience of presentation, and it should be clearly understood that the relationship between the Brachiopoda and the Mollusca is remote, both stocks having independent origins and very different ancestors, as will be seen in the further consideration of them. The mere fact that brachiopods have two valves somewhat similar to the two shells of bivalves such as oysters, mussels, etc., has no further significance than that in both stocks they are protective coverings for the soft bodies of the animals within.

There are other animals with external shells besides the Mollusca and Brachiopoda, and the terms lobster shells, crab shells, etc., are in popular usage. The coverings in these latter cases are composed largely of nitrogenous substances (chitin), yet they also have much carbonate of lime or phosphate of lime. While these animals are shelled, the biologist does not include them among the true shell-fish, and they are not considered in this chapter.

Brachiopods or Lamp Shells

(See Pls. 1, 2, 4, 9, 17, 22)

Geologic Occurrence. — Brachiopods are common fossils throughout the world in most of the marine formations of the Paleozoic and Mesozoic eras and are therefore of especial importance as index fossils in Stratigraphy and Historical Geology. They are present in the very oldest beds of the Lower Cambrian, but in few forms, though at times abundant in numbers. However, long before the end of this period at least three of the four orders into which the class is divided were in existence. This means that brachiopods origi-

nated in the later part of the Proterozoic era. There are about 160 living forms and fully 7000 fossil species. Brachiopods were in greatest profusion in the Paleozoic, there being in North America alone more than 2100 kinds restricted to this era. Throughout the Mesozoic, however, our continent was poor in brachiopods, less than 75 species being recorded, while in Europe the seas swarmed with them. In the Cenozoic they no longer are a conspicuous class of fossils, their number being greatly reduced, and probably at no time in this era were there more species than are living today. In North America less than 20 Cenozoic forms have been recovered. It was in the Ordovician that the brachiopods began to bloom out into varied forms and the class had its evolutional culmination in the Devonian, where 30 per cent of the American Paleozoic species occur. There was then more or less of a decline throughout the Carboniferous and a marked vanishing of stocks during the Permian period. In the late Triassic a new evolution set in, especially marked in the succeeding Jurassic in certain brachiopod stocks known as the rhynchonellids and terebratulids, whose descendants are most abundant in the present seas. The genera *Lingula* and *Crania* are believed to be the longest-lived kinds of animal stocks known, having persisted through all the physical changes since the Cambrian.

Habitat. — All brachiopods are sexed, gregarious, marine animals, living from the strand-line down into the great oceanic abyss of more than 3 miles in depth. Their greatest abundance, however, is in the shallow water down to 1000 feet, where fully 80 per cent of the living forms occur, while 70 per cent live above 600 feet of depth.

Arm Structure. — The word Brachiopoda means *arm-footed* and was given to the group because of a false physiological interpretation of the brachia or arms, for the animals do not crawl on their arms as was thought in 1806 when the word was coined (see Figs. 371, 372). The two more or less looped or spirally rolled, fleshy, fringed arms, on the contrary, serve two functions: first, through movements of the cirri and their cilia (the fringe) they attract currents of water into the shell, where the microscopic food, chiefly algæ, is extracted from it and fed into the mouth; second, they serve for respiratory purposes, that is, for the absorption of the oxygen so necessary for sustaining the vital force.

In many brachiopods the arms are unsupported by internal calcareous skeletons, but in the majority there are such supports and they are of much value in the zoölogical classification of these

lowly animals (see Figs. 371, 372). The most primitive supports consist of two short, sickle-shaped hooks known as *crura*. When these are more or less long and united in the middle, they are called

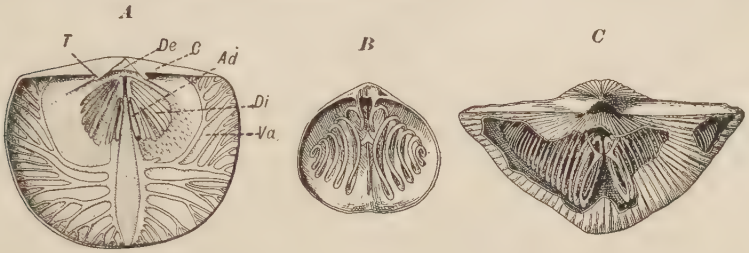


Fig. 371. — Internal characters of brachiopods. *A*, ventral valve of a strophomenid (*Rafinesquina expansa*). *B*, dorsal valve of a spire-bearer (*Nucleospira*), showing the skeleton that supports the arms. *C*, both valves with the dorsal shell broken to show the spiralia (*Spirifer striatus*). After Davidson. *Ad*, adductor scars; *C*, cardinal area, which also makes the hinge of the valves, and to which are attached the teeth (*T*); *De*, open delthyrium where the pedicle emerged; *Di*, diductor muscle scars; *Va*, vascular markings.

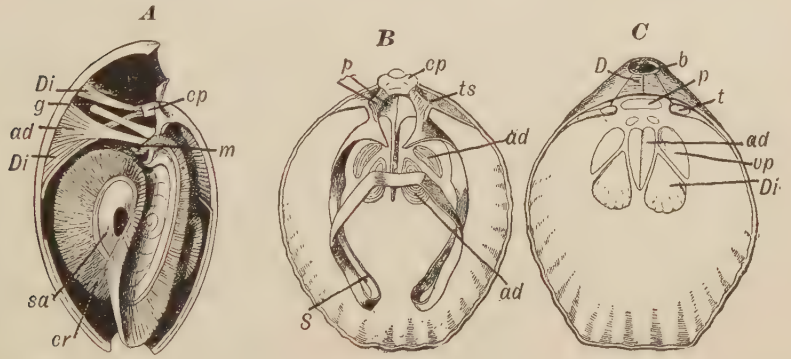


Fig. 372. — Internal structures of a loop-bearing brachiopod (*Magellania flavescens*). After Davidson, from Zittel's *Handbuch*. *A*, the shell and animal in section from the side. *B*, dorsal interior with loop or skeleton that supports the arms. *C*, ventral interior, showing muscle scars. *ad*, adductor muscles, two in ventral and four in dorsal valve; *b*, foramen through which pedicle emerges; *cp*, cardinal process to which are attached the ventral diductor muscles (*Di*); *cr*, cirri on edges of arms; *D*, two deltidial plates closing delthyrium; *Di*, diductor muscles that cross over to the cardinal process (*cp*); *g*, gut ending blindly; *m*, mouth area; *p*, place where pedicle is attached to shell; *S*, calcareous loop; *sa*, fleshy arms covering loop; *t*, teeth; *ts*, grooves into which articulate teeth of ventral valve; *up*, ventral pedicle muscles.

loops (Fig. 372 *B*), shells of this type being common after the Paleozoic; but when they bend outward into spiral coils, they are referred to as *spirals*, a type seen chiefly in the Paleozoic (Fig. 371 *B* and *C*).

External Structure. — Brachiopods have two valves (shells) which are situated on the ventral (belly) and dorsal (back) sides of the animals, and are hence known as the dorsal and the ventral valves (Fig. 373). In bivalved molluscs, on the contrary, the shells are on the right and left sides of the animal, and are therefore called the right and the left valves. In addition, the soft parts of these two types of invertebrates are markedly different. Issuing from the ventral valve in the brachiopods there is a short, or in some types a very long, worm-like body known as the peduncle or pedicle (Fig. 373 *A*), a fleshy stem, which in the great majority of cases anchors the animal to some foreign object on the sea bottom, and the individuals stay throughout life fixed to one

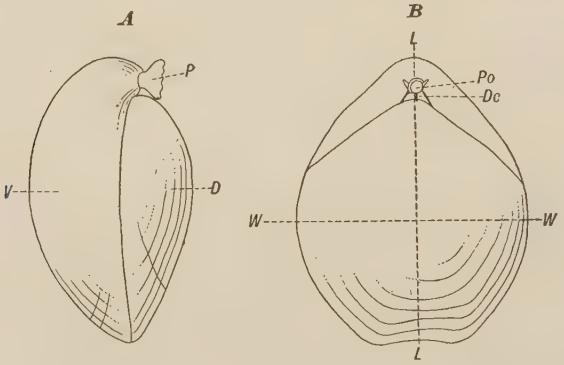


Fig. 373. — Diagrams of a lamp shell or brachiopod from the side (*A*) and dorsal view (*B*). *D*, dorsal valve; *Dc*, delthyrium, closed by two deltidial plates; *L*, length of shell; *P*, short pedicle by which the animal is permanently attached to foreign objects; *Po*, pedicle opening or foramen; *V*, ventral valve; *W*, width of shell.

place, the new-born young alone being free, and remaining unattached for some days or, rarely, two to three weeks. It is only exceptionally that brachiopods in later life are without a peduncle and then the ventral valve is more or less cemented to some hard object, or otherwise held in place.

The shells of brachiopods are either phosphatic (phosphate of lime) or wholly calcareous (carbonate of lime). When phosphatic, they are usually thin and do not have ventral *teeth* and dorsal *dental sockets* or *hinge-lines* for the hinging or articulation of the valves (Figs. 371 *A*, 372 *B* and *C*); such forms are said to be inarticulate, this structure being used in dividing the brachiopods into two subclasses, the *Inarticulata* and the *Articulata*. All of the calcareous-shelled brachiopods are more or less well hinged

and therefore articulate. The shell substance is said to be *impunctate* when there are no minute perforations passing through, and *punctate* when there are closely set canals in the valves. These cannot be seen with the naked eye, but with a pocket lens any punctate brachiopod is readily made out.

Internal Characters. — The shells are secreted by the *mantle*, which consists of two thin membranes that are not united marginally and have the form of the inside of the valves. They completely cover the soft parts of the animal, like skins, and their inner surfaces are respiratory, as are also the brachia (arms) within the front mantle cavity.

On the inside of the two valves are usually seen *muscular impressions*, or markings on the places where the muscles were attached. These scars are different in the dorsal and ventral shells, and more or less variable throughout this class of animals. Only the most important and largest of them need, however, be mentioned. In the ventral valve in the middle line are two small elongate scars called the *adductor impressions* (Fig. 372 *A* and *C*). These represent the places of attachment for the adductor muscles, or those which by contraction close the shell. The adductors pass over to the dorsal side, where they divide and are attached in four places, making the only prominent scars of the dorsal valve (Fig. 372 *B*). On each side of the adductor impressions in the ventral valve are two large *diductor scars* (Figs. 371 *A*, 372 *C*), left by the diductor muscles, which open the shell and which pass backward to the posterior region of the dorsal valve and are there attached to a protuberance known as the *cardinal process* (Fig. 372 *A* and *B*).

Mollusca or Shell-fish

Nature of Mollusca. — The Mollusca present a greatly diversified array of bilaterally symmetrical animals popularly known as shell-fish, of which it is estimated that fully 45,000 kinds are now living. Such are the clams, oysters, snails, and the pearly nautilus. They are soft-bodied animals, often inhabiting shells to protect themselves against their enemies, though there are many without the protective shells. The general term by which naturalists speak of them is Mollusca, meaning soft. As a rule, they are very sluggish and have unsegmented bodies. Though they are devoid of limbs for crawling or swimming, most of them do, however, move about, accomplishing this by means of the so-called *foot*, a creeping sole situated underneath the belly. Usually the

body is covered by a *mantle*, a thin membrane that secretes the shell when such is present. Within the *mantle cavity* lie the *gills*, organs of varied construction setting up currents of water, out of which is extracted not only the oxygen for respiration but often also the food for life sustenance. In the land snails there are no gills and here the mantle cavity has been adapted into a kind of lung for aërial respiration, since they breathe the air. In all of the molluscs, except the bivalves, the mouth is furnished with a flexible chitinous ribbon known as the *radula*, a sort of tongue, usually provided with numerous minute, sharp, hard teeth and moved by special muscles for the breaking up of the food. The sexes are separate, or united, the individuals in the latter case being hermaphrodites.

Habitat. — The chief habitat of the Mollusca is the shallower parts of the seas and oceans, but some live in the fresh waters of the land, and the snails even live abundantly on the land at all altitudes where there is vegetation.

Nature of the Shell. — The shells usually consist of three layers: an outer, very thin, brown, horny layer always absent in the fossils; a thick, middle, limy layer referred to as the porcelanous ayer, the one most often preserved in the rocks; and an inner, generally thick, mother-of-pearl, prismatic layer that is often destroyed in the fossils, especially among the Paleozoic molluscs, since it consists of an easily dissolvable form of carbonate of lime known as aragonite.

For the purposes of Historical Geology only three classes of molluscs need be studied, namely, Lamellibranchia, Gastropoda, and Cephalopoda.

Lamellibranchia

The name Lamellibranchia comes from *lamella*, meaning *leaf*, and *branchia*, meaning *gills*, and was chosen because in these molluscs the gills are leaf-like. The class is also widely known as *Pelecypoda*, meaning *hatchet-foot*, because the foot often has the shape of a hatchet (Figs. 374 *A* and 375 *A*). The group includes all the headless and therefore *degenerate Mollusca*. The body is usually compressed from side to side and always covered with two shells or valves, one on the right, the other on the left side (Fig. 374 *A* and *B*). They are therefore often called *bivalves*, and are popularly known as mussels, clams, oysters, cockles, and scallops. Their habitat is mostly marine, in the shallow waters near the shores, where their food, the microscopic algæ, is most abundant.

Nearly all fresh waters, however, have some mussels, but none have been adapted to live out of the water on the land. The food is strained out of the water by the gills (actually the labial palps), which are also the breathing organs. The lamellibranchs are very sluggish animals, many remaining buried in the sand and muds of

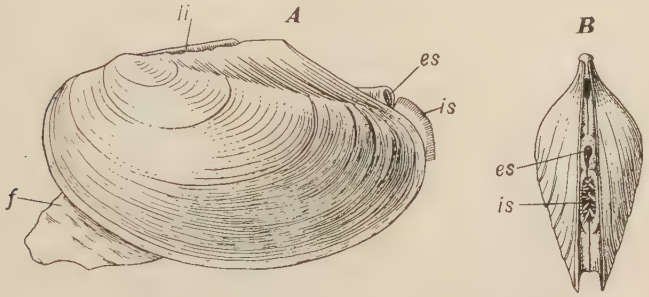


Fig. 374. — A fresh-water pearl shell (*Anodonta*). *A*, animal as seen from the left side. *B*, from the posterior end. After Howes. *es*, exhalant siphon; *f*, digging and crawling foot; *is*, inhalant siphon; *li*, ligament that opens valves.

the sea (Fig. 375 *A*). The scallops only can swim a little by clapping their valves and forcing water alternately from one side and then the other.

Shell Characters. — The two shells lie on the right and left sides respectively and are joined on the dorsal side of the body by a *hinge*, a more or less thickened area provided with teeth and sockets, allowing the valves to move upon one another (Fig. 375 *B* and *C*). Either on the outside or within the thickened shell mass of the hinge area there is an *elastic ligament* attached to both valves that acts like a spring and keeps the shells open when the animals are in repose (Fig. 374 *A*). On the inside of the valves are muscle scars, usually one at each end of the shell, these being due to the *anterior* and *posterior adductor muscles*, though in many forms, as in the oysters, there is only one of these scars situated near the center of the valve (Fig. 375 *B* and *C*). These muscles close the shell, and when it is shut the elastic ligament is under strain ready to open the valves again as soon as the adductors let go their pull. The wedge-shaped *foot* of the lamellibranchs is large in the creeping forms but more or less reduced in size through disuse, according to whether the animals live in holes, like the soft clam, or have one shell firmly cemented to some hard object on the sea bottom, as in the oysters.

Siphons. — In most lamellibranchs the mantle elongates beyond the shell into two tubes or siphons through which the water of res-

piration enters and leaves the mantle cavity (Figs. 374 *A*, 375 *A*). When the siphons are large, it is an adaptation for living buried in the sand or mud, and all lamellibranchs with such siphons have the shells marked on the inside by a decidedly bent line, the *pallial sinus*, seen in connection with the posterior adductor muscle.

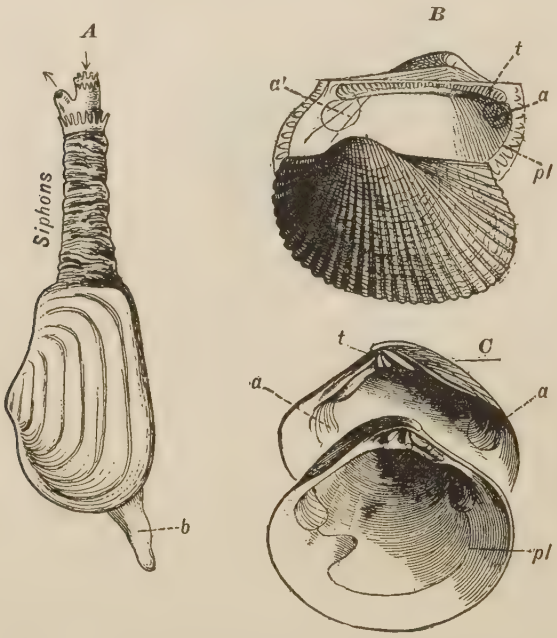


Fig. 375. — Bivalves. *A*, marine bivalve (*Mya*) that lives buried in the mud. The long, partially retractile tube is the outer covering of the siphon. After B. B. Woodward. *B*, the two valves of *Arca* from the outside and inside. *C*, another type of bivalve (*Meretrix*). After Zittel's *Handbuch*. *a*, adductor or closing muscles; *pl*, pallial line where mantle is attached to shell; *t*, teeth of shell articulation.

Geologic Range. — Lamellibranchs were exceedingly rare in the Cambrian and were not well established until the Ordovician, after which time they became more and more abundant and are very prolific in all the shallow waters of the present oceans. While the shells of these bivalves are often abundant in the Paleozoic rocks, they are usually not well preserved until the Pennsylvanian, a condition seemingly connected with a rather thin porcelanous layer and a comparatively thick mother-of-pearl one, the latter being easily destroyed. They are only occasionally of value as stratigraphic markers in the Paleozoic, but, beginning with the Meso-

zoic, they are abundantly preserved and often serve as index fossils. Oysters appeared in the Mesozoic but were small and comparatively insignificant in species or individuals until the later Jurassic, since which time they have served as food for many diverse stocks of invertebrate and vertebrate animals.

Gastropoda

General Characters. — The name Gastropoda means *stomach-footed*, and has reference to the fact that the animals creep about by contractions of the sole of the foot, which lies on the ventral side (Fig. 376 *B* and *C*). This class of molluscs, which are as a rule sluggish, though less so than the lamellibranchs, is exceedingly varied and embraces not only such shelled forms as the limpets, drills, periwinkles, whelks, conchs, and snails, but also the naked sea slugs and the slugs of the land. They are most abundant and varied in the shallow seas, where they crawl over the bottom, are far less varied in fresh water, and on the land are represented by the vegetarian, air-breathing or pulmonate snails (so-called because the mantle cavity acts as a lung in respiration, see Fig. 376 *C*), which are found in nearly all places where plants grow, and are very varied the world over. The mantle cavity in the aquatic forms usually has but a single gill, the one on the right side, that on the left side having been lost because of the spiral form of the body. In habit they are, as a rule, herbivorous, less often carnivorous and scavengers. The mouth is provided with a radula or tongue-like process. The carnivorous forms known as drills

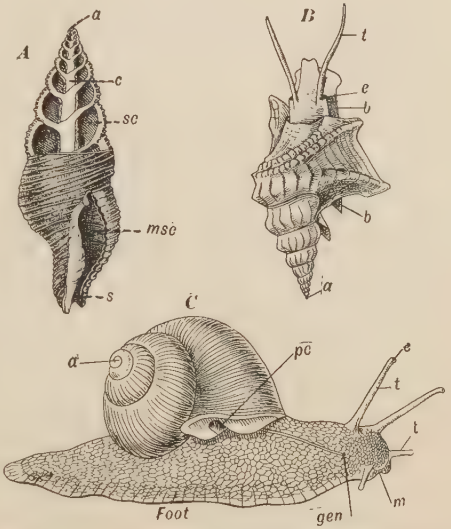


Fig. 376. — Gastropods. *A*, regular marine gastropod (*Latirus*), with the spiral shell wound to the right (dextral). After Steinmann. *B*, another marine gastropod (*Aporrhais*), with the animal crawling. After B. B. Woodward. *C*, an air-breathing (pulmonate) land snail in the act of crawling, the head with pairs of sensory tentacles, the long ones bearing eyes. After Hatschek and Cori. *a*, apex of shell; *b*, foot; *c*, interior columella; *e*, eye; *gen*, genital opening; *m*, mouth; *msc*, mouth of shell cavity; *pc*, opening into pulmonary cavity; *s*, siphonal cavity; *sc*, interior shell cavity; *t*, sensory tentacles.

bore holes into their shelled victims, such as the clams, with the radula and the aid of a weak secretion of sulphuric acid. The head of most gastropods is usually distinctly marked off from the rest of the body, and has a pair of eyes and one or two pairs of sensory organs or tentacles (Fig. 376 *B* and *C*).

Spiral Shell. — The usual form of the shell or protective covering is a spirally twisted, right-handed (dextral) cone with the apex directed upward (Fig. 377 *C*); it is secreted by the mantle situated on the dorsal side of the animal. Because of this single shell, the gastropods are also spoken of as *univalve molluscs*. In many forms, however, there is a chitinous or calcareous *operculum*, a plate attached to the side of the foot, which closes the shell opening when the animal has retreated into its shell or is retracted. Even though gastropods may thus have two shells, these together do not represent the two valves of bivalves. It is only the spiral

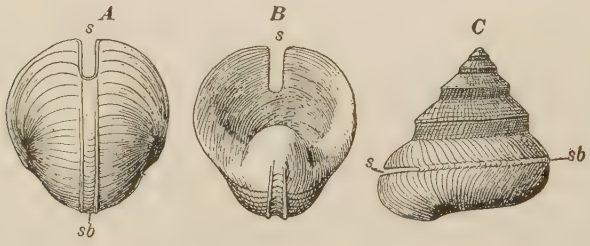


Fig. 377. — Two species of primitive marine gastropods. *A*, *B*, a form wound in a plane (*Bellerophon*). *C*, a form with a depressed spire (*Pleurotomaria*). After Zittel's *Handbuch*. *s*, slit or opening for siphons; *sb*, slit-band, the progressive track of the slit.

cone that corresponds to the valves, because the operculum is a secondary structure not present in all univalves, is secreted by the foot, and has nothing to do with the dorsal mantle or true shell secretion.

Geologic Range. — Primitive forms of Gastropoda were present in the Lower Cambrian, where practically all of them were more or less conical, not twisted, but resembling little hoods. The twisted type of cone appears more and more abundantly in the Upper Cambrian and since the Ordovician has been common as fossils. At present there are living more than 20,000 species, a larger representation than at any time during the geologic past. In the Paleozoic they are, as a rule, defective fossils and it is only since the Mesozoic that their abundance in well preserved specimens is of value in Historical Geology. The air-breathing gastro-

pods appear rarely in the Pennsylvanian and seem not to have been common until late in the Jurassic, where are also seen the first fresh-water snails. There are about 500 species of fossil pulmonate snails known and about 6000 kinds of land snails.

The *Pteropoda*, or sea butterflies, are in general a group of small, active, pelagic gastropods, highly modified and with very thin transparent phosphatic shells (Fig. 378). They spend their lives in the upper part of the oceanic waters. The foot is modified and flattened out into two lateral folds or wing-like structures (hence they are also called winged snails) by means of which the animal swims. The pteropods are often found fossil in the Devonian and subsequent rocks. Those of the early Paleozoic, however, were heavy-shelled forms with totally different habits, crawling on the bottom of the sea; these were the *Hyolithes* and *Tentaculites* which were common in Cambrian to Silurian time. In the Middle Ordovician there was also a great abundance of minute pelagic gastropods known as *Cyclora*, which had very thin phosphatic tests. Their interest in this connection is that in Tennessee they are so common in the Ordovician limestone that when these rocks are decomposed into a residual red clay, the Cycloras remain undissolved and concentrated as a phosphate of lime, which is much sought after for fertilizing purposes.

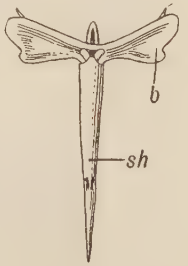


Fig. 378. — A sea-butterfly or pteropod (*Styliola*). Much enlarged. After Adams, from Zittel's *Handbuch*. *b*, foot or fin, the swimming organ; *sh*, shell.

Cephalopoda

Cephalopoda (means *head-footed*) are the most highly organized Mollusca and include such animals as the nautilus, ammonites, octopus, cuttlefish, and squid. All are exclusively marine. The two former types of cephalopods have chambered shells in which the animals live, while the latter stocks are devoid of these, though in the cuttlefish and squid there is more or less of an internal skeleton often preserved as fossils. In the Mesozoic there lived abundantly another stock known as the belemnids, with thick cigar-shaped internal skeletons that occur abundantly among fossils. For present purposes the nautilids only will be described, because they are decidedly characteristic of the Paleozoic, and the remainder will be considered when Mesozoic animals are studied, for their chief development lies in that era (Chapter XLVIII).

Pearly Nautilus (see Fig. 379). — The nautilids are the oldest and most primitive division of the class Cephalopoda. They were sparingly present in the Upper Cambrian, and had an abundant Paleozoic representation beginning with the Ordovician. The word nautilus is a poetic form of the Greek word for sailor, and like their distant relatives, the argonauts, it was believed that these animals could

expand certain of their arms into the wind and so sail the seas. This idea, however, is wrong, for the four living species of the genus *Nautilus* now inhabiting Oceanica from the Malay region to the Philippine and Fiji islands have never been seen at the surface except in a dying condition, though their empty sealed

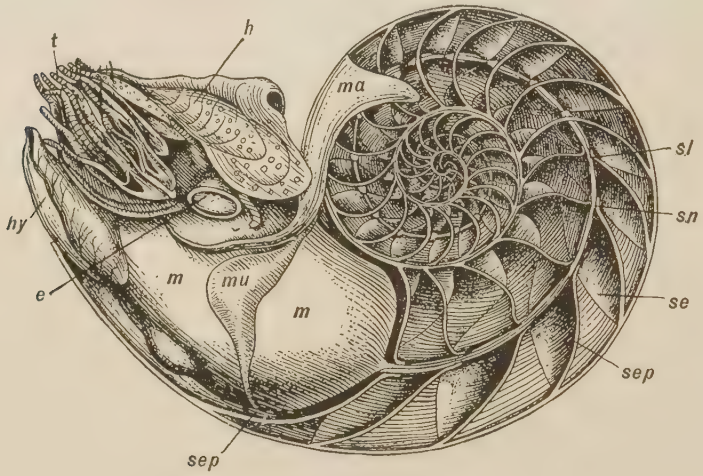


Fig. 379. — Pearly nautilus, with the shell cut through center to show internal chambers; the animal is fully expanded to show all of the external characters. $\times \frac{1}{2}$, After Hancock. *e*, large eye; *h*, hood or protective covering for the animal when retracted into the shell; *hy*, hyponome or funnel where water leaves mantle cavity; *m*, mantle, which encases animal and secretes shell (note prolongation into siphuncle); *ma*, dorsal prolongation of mantle; *mu*, muscle attaching animal to shell; *se*, chambers; *sep*, shell partitions or septa; *si*, siphon and siphuncle extending from animal through all the chambers to apex of shell; *t*, tentacles around mouth.

shells drift to Japan, Africa, and New South Wales. The nautilids are gregarious animals of the deeper and warmer sea between 300 and 600 feet, at a temperature of 68° F., but they have been taken in 1000 feet of water. In habit they are fierce and decidedly carnivorous and will take the meat that baits the fish-pots at depths down to 420 feet.

The popular name, *pearly nautilus*, is derived from the fact that these beautiful, bilaterally symmetrical shells are often used as ornaments and for pearl buttons, after the thin, outer, porcelanous, striped layer has been removed from the much thicker, inner, mother-of-pearl one. They are also known as *chambered shells*, because the cone, of whatever form it may be, is regularly chambered by thin, pearly, transverse partitions called *septa*, which

the animal secretes at regular intervals along the posterior side of its body after it has moved a short distance forward in the living chamber. These septa are concave toward the opening of the shell, and are perforated by a circular hole which terminates behind in a funnel. Through this funnel and the perforations there passes a fleshy tube known as the *siphon* (Fig. 379, *si*), originating on the rounded posterior side of the animal and continuing through all the chambers to the final minute one at the apex of the cone, where it is fastened to the inner side of the wall. In many fossil forms the siphon has secreted a calcareous tube, either straight or bent, known as the *siphuncle*, which at times is very thick; whatever may be its nature, it is thought to have been porous, permitting the animal to send through it into the chambers a gas to make the shell more or less buoyant, and thus to render the weight of its stony house but little of an encumbrance in its movements. The nautilids crawl over the bottom of the sea, or hold to it by their ninety retractile tentacles, and can swim rapidly backward in a jerky manner by forcing out water through the *hyponome* or *ambulatory funnel*, which consists of two flaps, the thickened ends of the mantle that envelops the animal and meets in the middle of the ventral side (Fig. 379, *hy*). To the sides of the cone the septa are firmly united, but in the fossils it commonly happens that the outer shell is lost, in which case the edges of the partitions show plainly as so many lines in the rock-filled cone. As the nature of these lines is of much importance in classifying shell-bearing cephalopods they are termed *suture lines*. Usually these suture lines are straight, but there are forms in which they are decidedly bent in lobes. These, when convex toward the apex of the cone or backwardly directed, are termed *lobes*, and when curved toward the larger end or aperture of the shell, are called *saddles*.

Nature of the Fossil Forms. — Nautilids appeared in fair abundance in the Lower Ordovician. Among these the most primitive were straight, tapering cones that were circular or oval in outline, and because there are many families of them they are called *Orthoceracones* (from the genus *Orthoceras*, meaning *straight horn*, Pl. 5, Fig. 17). These orthocerids were common throughout the Paleozoic and particularly so in the Ordovician and Silurian, when individuals are known that originally had a shell as long as 15 feet (*Endoceras*). With the Devonian these primitive forms began to wane slowly, but some were still present in the Triassic. All other types of cephalopods had their origin in the straight-shelled Orthoceracones and the first of these had their cones slightly

bent and are therefore called *Cyrtoceracones* (from *Cyrtoceras*, meaning *bent horn*, Pl. 5, Fig. 18); later descendants were coiled in a loose spiral wound in a plane and are known as *Gyroceracones* (from *Gyroceras*, meaning *round horn*); still others are tightly wound, with the whorls embracing one another more or less closely, as in *Nautilus*, and these are termed *Nautilicones*. On the sides of such one sees more or less of the inner whorls of the shells, and the area of these whorls is spoken of as the *umbilicus*. It is small in *Nautilus* and wide or open in the Ordovician forms. The bending of the tubes is due to a more rapid secretion of lime along the ventral side of the cone, and the greater the unequal growth the more rapidly the cone involutes or rolls up. Nautilids persisted into the Mesozoic and were most abundant in the earlier half, after which time they gradually disappeared and are seen to-day only in the four relic forms, which give us our sole knowledge of the soft parts of the many thousands of kinds that swarmed the ancient seas.

Cephalopods are divided into two subclasses, the Tetrabranchiata and Dibranchiata, on the basis of the number of plume-like gills used to oxygenate the circulatory blood. In the former subclass there are four gills (*tetra*, four), and the latter division has but two. The Tetrabranchiata, all of which have external shells, appeared in the Cambrian, and have now almost vanished from the earth, while the Dibranchiata, which are in almost all cases naked but may have internal vestiges of the ancestral outer shell, arose in the Triassic and are abundantly represented among living cephalopods by the squids, argonauts, and octopus.

Below the visceral sac is situated the large *mantle cavity* with its gill-plumes, where water is freely taken in and passed out through the funnel. When the animal wishes to swim, however, the two flaps of the mantle are appressed, forming the funnel, and by a rapid contraction of the mantle or gill chamber the inhaled water is shot out with great force. The animal then darts backward or sidewise according to the direction in which the stream is ejected. They are expert and rapid swimmers, according to Wiley. The eyes on either side of the head are large, of primitive structure, and supported on short stalks called peduncles. The mouth is surrounded by the tentacles and is provided with two powerful, protrusible, horny, parrot-like bills, the upper one of which among fossil forms was often tipped with a carbonate of lime beak.

CHAPTER XXXIV

ORDOVICIAN TIME AND THE REIGN OF INVERTEBRATE ANIMALS

General Characteristics. — The Ordovician system of rocks lies above the Cambrian and beneath the Silurian systems. It represents the closing period of the Early Paleozoic sub-era, during which the marine invertebrate animals were the highest expression of life. Fully 1000 species are known from the Cambrian, whereas the Ordovician has at least five times as many described forms. The period was, therefore, one of marvelously great evolutional progress. As the land flora of this time seems to have been too soft and perishable for preservation in the sediments, practically nothing of it has been recovered, while the fragments of fishes abundantly preserved in Colorado, South Dakota, and Wyoming, but nowhere else, are negligible. We may therefore characterize the Ordovician as the time of marine invertebrate dominance, since all the grander divisions and subdivisions of this type of animals were then represented (see Pls. 4–6).

Fig. 380. — Adam Sedgwick, at the age of forty-seven. Author of Cambrian and Devonian systems.

History of the Term Ordovician.—It was Professor Lapworth of Birmingham University in England who in 1879 proposed the term *Ordovician* (after an ancient tribe, the Ordovices, who at the time of the Roman Empire lived in Wales) to replace the Lower Silurian of Murchison (1835).

Sedgwick first studied these beds in Wales (1831) and he contended for many years that they should be called Cambrian, but this latter name has been restricted to his Lower Cambrian, in which he found no fossils. In many parts of Europe Lower Silurian is still used for this, the second period of the Paleozoic, but it certainly is not conducive to clear thinking to refer to two systems by the

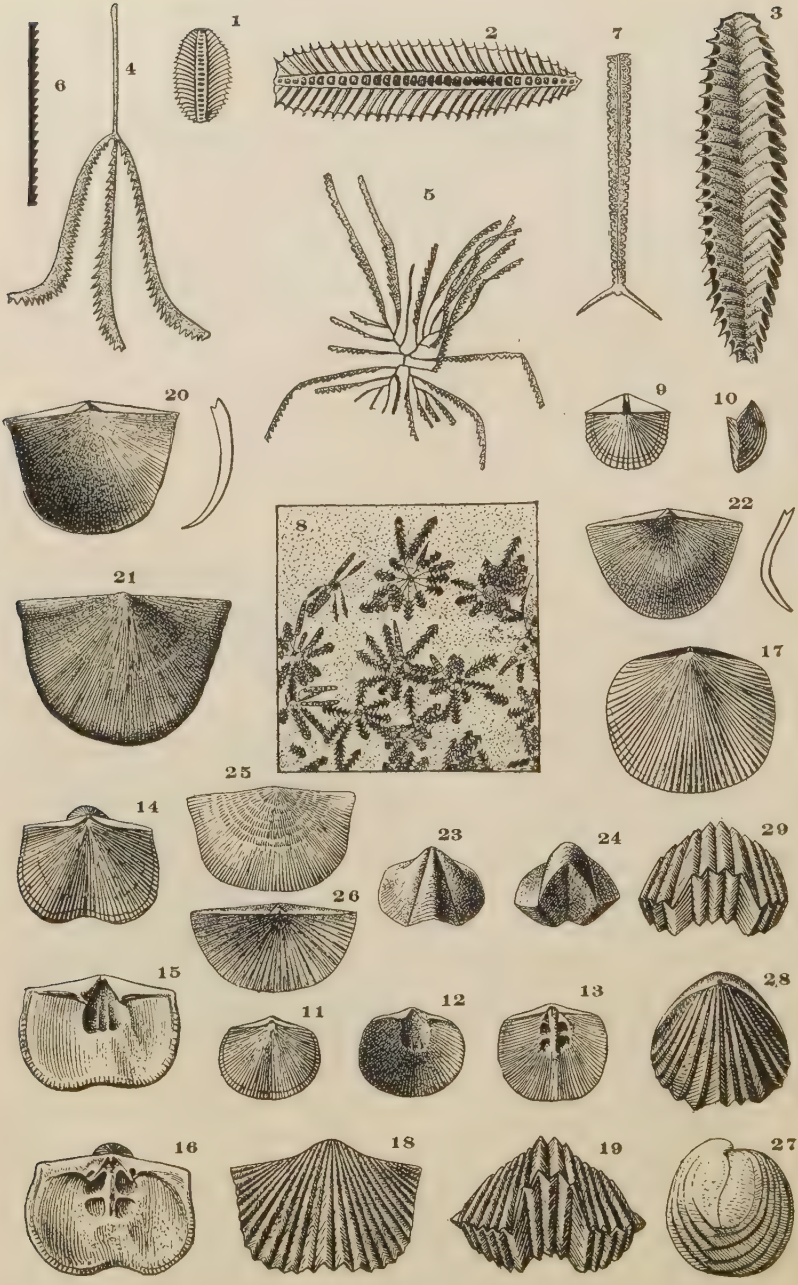


Plate 4. — Ordovician graptolites (1–8), and brachiopods (9–29).

See Appendix B.

one name of Silurian and to speak of them individually as Lower Silurian and Upper Silurian, thus giving the impression that the two systems are but parts of one — the Silurian. In the type area of the Silurian in England, each division has its independent faunal characters, and, furthermore, they are separated by an unconformity. Consequently, for the sake of fixity in nomenclature, geologists are gradually accepting, though under protest, Lapworth's substitution of Ordovician for Lower Silurian. But if Ordovician, as now widely used, can be shown to embrace two or even three systems, the time will have arrived for a redefinition of both Cambrian and Ordovician.

Ordovician System of Rocks

Acadian Area. — Throughout most of North America the beds of Ordovician time are in the main of limestones, with some calcareous shale, and the period may well be spoken of as one essentially of limestone making. However, throughout the New England States, other than Vermont, and the Maritime Provinces of eastern Canada south of the St. Lawrence River, wherever Ordovician strata are known, they are dark to black shales and greenish sandstones with but little limestone, ranging in thickness from a few hundred up to more than 2000 feet. This region is an independent marine province and belongs to the Atlantic realm, much of its life being more like that of western Europe than of the closely adjacent Central Interior sea. The region was more or less in connection with the Central Interior sea, but only at one time did it markedly feel the latter's influence, and this was toward the close of the Middle Ordovician, when the late Trenton sea was invaded by the Atlantic fauna and its dark, muddy waters.

Logan's Line. — As one steams down the majestic St. Lawrence from Montreal to Quebec, there are seen on the left or north side of the river the little disturbed and nearly horizontal Middle Ordovician strata resting against the Laurentian Hills, which are first discerned in the distance and come nearer as one approaches Quebec. On the south side of the river, however, all the way to the land's end at Gaspé, the Ordovician strata are in confusion — a folded, crumpled mass of great thickness, known to Canadian geologists as the Quebec series, and naturally presenting many difficult problems of stratigraphy. To the north of the river are the remnants of the Early Paleozoic sediments deposited by the Central Interior sea, while to the south is the Acadian mass of sediments of the same and later time, laid down by still another sea having Atlantic connections. This latter material has been thrust, no one as yet knows how far, upon the strata of the other sea province. The river therefore runs along a fault line, first determined by Logan, and hides the contact between the two series all the way from Anticosti to near Montreal; then the fault leaves the course of the river and turns sharply south, continuing to Lake Champlain, where it may be seen at many places along the eastern shore of the lake. From here the fault line continues southward to Troy and Albany, where it crosses the Hudson River and gradually loses itself in southern New York. The northwesterly moved

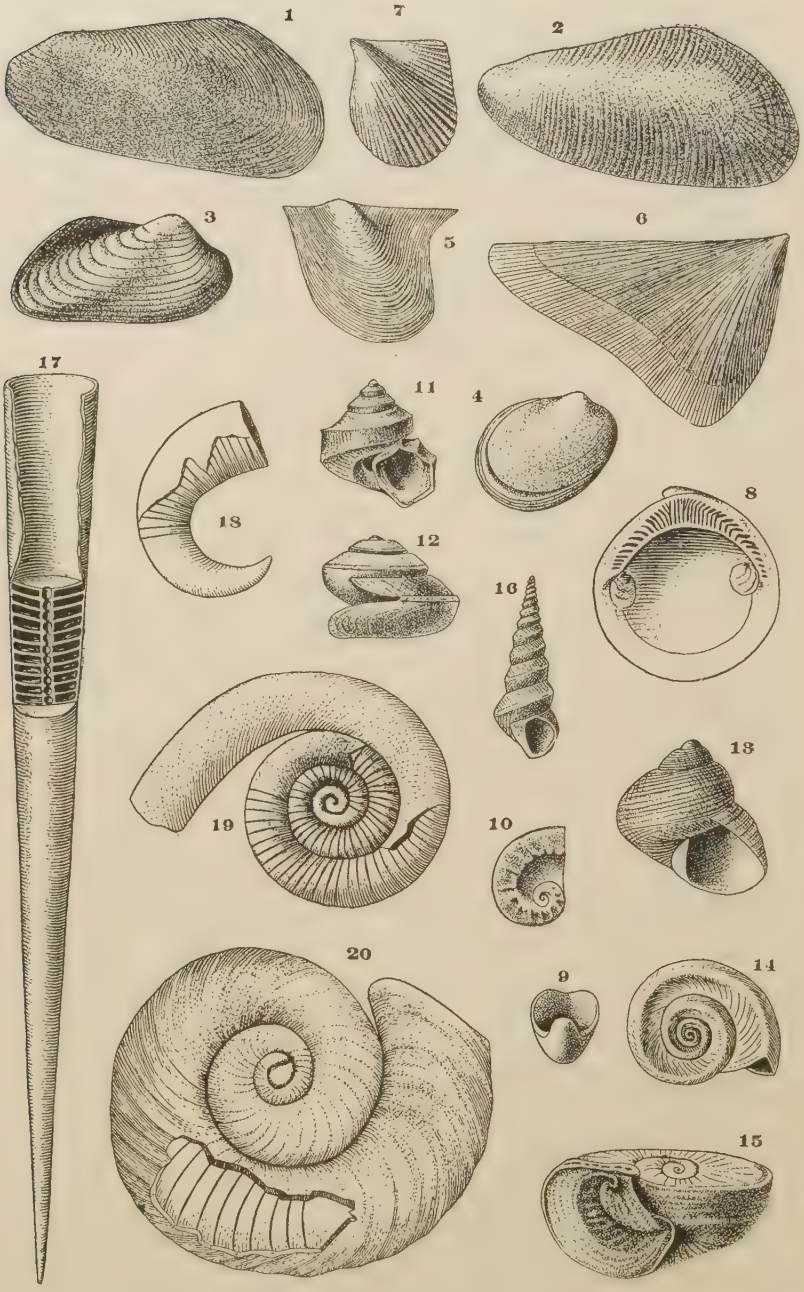


Plate 5. — Ordovician bivalves (1–8), gastropods (9–16), and cephalopods (17–20).

See Appendix B.

mass of Acadia faces the rugged Laurentides, and between them lie the placid St. Lawrence and the remnants of the still horizontal deposits of the Central Interior sea. The great marble quarries of Rutland, Vermont, are like open foundations which permit us to look below the once existing overthrust masses at the limestone floor below. These limestones were laid down by the Central Interior sea and are the continuation of the unmoved remnants along the north side of the St. Lawrence River.

Logan's line is not thought to have been made in Ordovician time, but was one of the major results of the Devonian disturbance (Shickshockian) and the Appalachian Revolution which occurred toward the close of the Paleozoic.

Interior Region. — In the interior of North America the Ordovician seas were, in the main, clear-water ones, depositing calcareous materials and largely limestones. Toward the margins of these seas the sediment was greatly increased by the addition of much mud and some sands. In a broad, general way it may be said that there are in the middle Appalachian region from 6200 to 9700 feet of Ordovician strata, thinning down in the Mississippi valley to, at most, 1900 feet and in many places to less than 1000 feet.

Rocky Mountains Area. — In the Rocky Mountains region the greatest thicknesses are in Nevada and Utah, where there are Ordovician limestones, essentially Lower Ordovician ones, between 3000 and 5000 feet thick. These deposits thin down rapidly northward and also eastward, but in British Columbia they again thicken to the northward, for in the Mackenzie valley there appear to be more than 4000 feet of limestones, dolomites, and shales.

Areas of Greatest Sedimentation. — The limestones are most dominant and in greatest mass in the Lower Ordovician and are essentially magnesian and locally even dolomites. We have here the same geographic position of masses of sediments seen in the Cambrian, a phenomenon that is repeated throughout the Paleozoic, namely, the proximity of the greatest volumes of sediments to the eastern and western land masses (Acadia, Appalachia, Cascadia), while in the northern interior seas the volume is less than one fifth that of the Appalachian trough. The detrital materials came, therefore, from the marginal lands, and very little matter other than that precipitated from solution was derived from the far larger northern land, Laurentia.

Climate of Ordovician Time. — The vast limestone and dolomite accumulations of Ordovician time throughout North America, which have an abundance and great variety of life even in the Mackenzie valley and arctic Alaska, point to warm and equable waters. The same Middle Ordovician reef corals that are found in Tennessee and New York occur also in Baffin Island, the Mac-

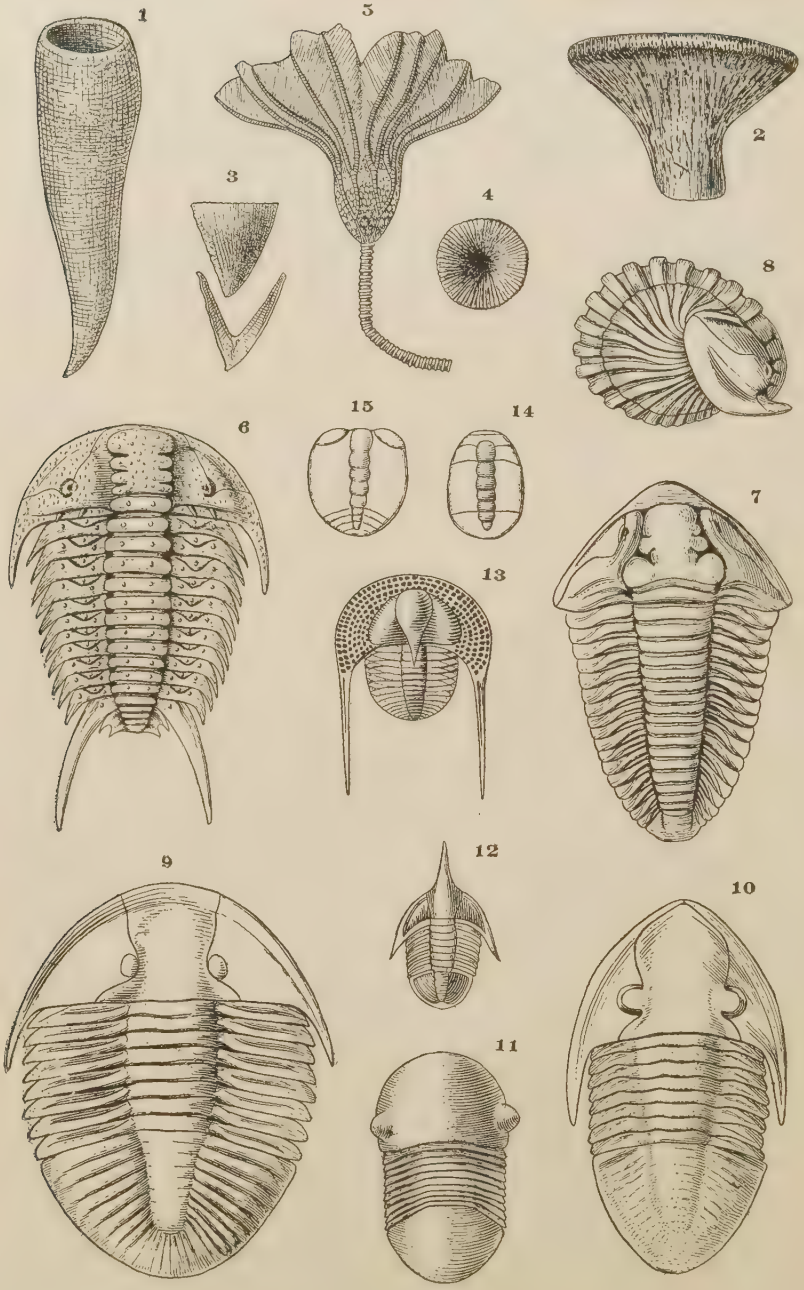


Plate 6. — Ordovician sponges (1, 2), cup corals (3, 4), crinid (5), and trilobites (6–15).
See Appendix B.

kenzie River valley, and Alaska, though they are less abundant in the far north. We may therefore assume that the temperature of the lands and the seas in the northern hemisphere was nearly everywhere the same, and that it was warm temperate throughout.

Divisions of the Ordovician Period

Basis for the Divisions. — Partly on the basis of the entombed fossils, but more particularly because of three distinct cycles of continental submergence, Ordovician time in North America is divisible into as many epochs of time, or series of strata. In each epoch the oceans invaded more or less of the land and then withdrew from the continent, if not entirely at least in great part. The first flood, or Canadian, was not of great extent, but the second, or Champlainian, and the third, or Cincinnatian, were the greatest of all Paleozoic time. These three epochs may eventually be recognized as of the value of periods, for the one of Middle Ordovician time had a duration not shorter than that of the Silurian. In that event they will be referred to in North America, not as parts of the Ordovician, but under distinct terms, probably the ones used below.

These three periods or epochs of the Ordovician are further divisible as follows:

Upper Ordovician or Cincinnatian	Gamache
	Richmond
	Maysville and Lorraine
	Eden and Utica
Middle Ordovician or Champlainian (Cambrian of Sedgwick)	Collingwood
	Trenton
	Black River
	Lowville
	Chazy and Stones River, St. Peter
Lower Ordovician or Canadian	Fort Cassin
	Beekmantown

Canadian or Lower Ordovician

Definition. — Dana proposed the term Canadian for this epoch in 1874, because, as he states, the strata and fossils were first distinguished and described in Canada by Canadian geologists. In no place has there been determined an unbroken deposition from the Upper Cambrian into the Canadian, but while there is an unconformity between them, it is never of a marked character. In other words, there was no appreciable deformation immediately preceding Ordovician time. The Canadian submergence was restricted to the Acadian area, the eastern United States, and the

Great Basin of Nevada and Utah. In the upper Mississippi valley, during the emergent time, that is, when the lands were dry, Upper Cambrian deposits were apparently exposed to a desert condition, and the sands were blown about, making the rounded sand grains which in the next epoch were gathered together to form the basal sandstone of the St. Peter invasion, now seen throughout the upper Mississippi drainage area. The paleogeography of this time is not yet well enough known to present a map of it here.

Life of the Canadian Epoch. — In the Acadian or Atlantic province the most characteristic fossils of the Lower Ordovician are the first true graptolites (*Tetragraptus* and *Phyllograptus*, see Pl. 4, Figs. 1–4;

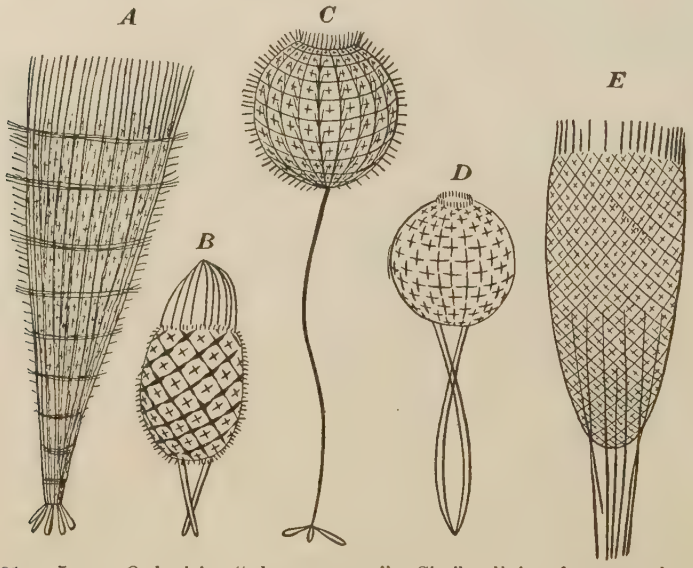


Fig. 381. — Lower Ordovician "glass sponges." Similar living forms are known as "Venus's flower baskets." After Dawson and Hinde. See Appendix B.

for further description of graptolites see Chapter XXXV). Otherwise these strata are poor in fossils, but occasionally most interesting algæ (Fig. 382) and sponges of the type of "Venus's flower basket" (Fig. 381) are found. The Central Interior sea, on the other hand, contained much life, but, on account of the magnesian character of the sediments, the fossils were generally destroyed through the chemical changes that occurred during their deposition. There are here many gastropods, some of them large and thick-shelled, and a variety of straight, bent, and coiled nautilids (see Pl. 5, Fig. 19) as the leading fossils. There are also many trilobites, but it is rare to find a whole one, and usually only heads and tails are seen.

Fig. 382. — Glaciated surface of the "Cryptozoön Ledge" at Lester Park, in township near Saratoga Springs, N. Y. Photograph by H. P. Cushing, N. Y. State Survey.

Champlainian or Middle Ordovician

Definition. — This division derives its name from the Lake Champlain area, where the New York geologists of 1838–1842 first studied and named its formations. It was a long epoch of time and one with much change between land and sea. The waters were oscillatory and variable, with a final great inundation from the Arctic, the first of a series of Paleozoic floods from this ocean. The maximum of the Champlainian submergence occurred early in Trenton time, when the Arctic flood had its greatest extent and seemingly covered about one half of the continent (see Pl. 7). More of Laurentia was then beneath the sea than at any other time since the beginning of the Paleozoic. Our knowledge of the Cordilleran sea of this time is not extensive, but there appears to have been a through waterway from the Great Basin country into the Arctic Ocean. Encroachments by the Atlantic Ocean were restricted to the northeast of the continent and this ocean sent but little of its life into the Central Interior sea. Finally, nearly all of the marine water was largely withdrawn, completing the ebb and flow of Champlainian time, and hence the diastrophic cycle.

Life of the Champlainian Epoch. — During no one of the Paleozoic inundations did the life of the sea record itself so completely by its fossils in the sediments as during the Champlainian epoch. The waters swarmed with a vast variety of invertebrate animals, and there are known more than 1600 species, chiefly of bryozoans (exceedingly small animals, remotely resembling corals), brachiopods, gastropods, cephalopods, and trilobites (see Pls. 4–6). There are about 300 kinds of brachiopods from these deposits in North America, and when the bryozoans are all described there will be nearly 450 species of them. The contribution of the latter as limestone makers, notwithstanding their minute size, Ulrich believes to have been twice as great as that of the brachiopods. There appear to have been as many kinds of gastropods as of brachiopods, but their mother-of-pearl shells were generally destroyed, like those of most of the bivalved molluscs and the nautilids. Trilobites are often common and well preserved and include more than 200 kinds, but in general they are neither large nor ornate (see Pl. 6). There must have been many siliceous sponges (like the glass sponges or "Venus's flower basket," Fig. 381), but, although good fossils of the thick-walled forms (Lithistidæ, Pl. 6, Fig. 2) are common in places, yet, as a rule, the sponges are conspicuous by their absence. Crinids (animals related to the star-fishes but fastened to

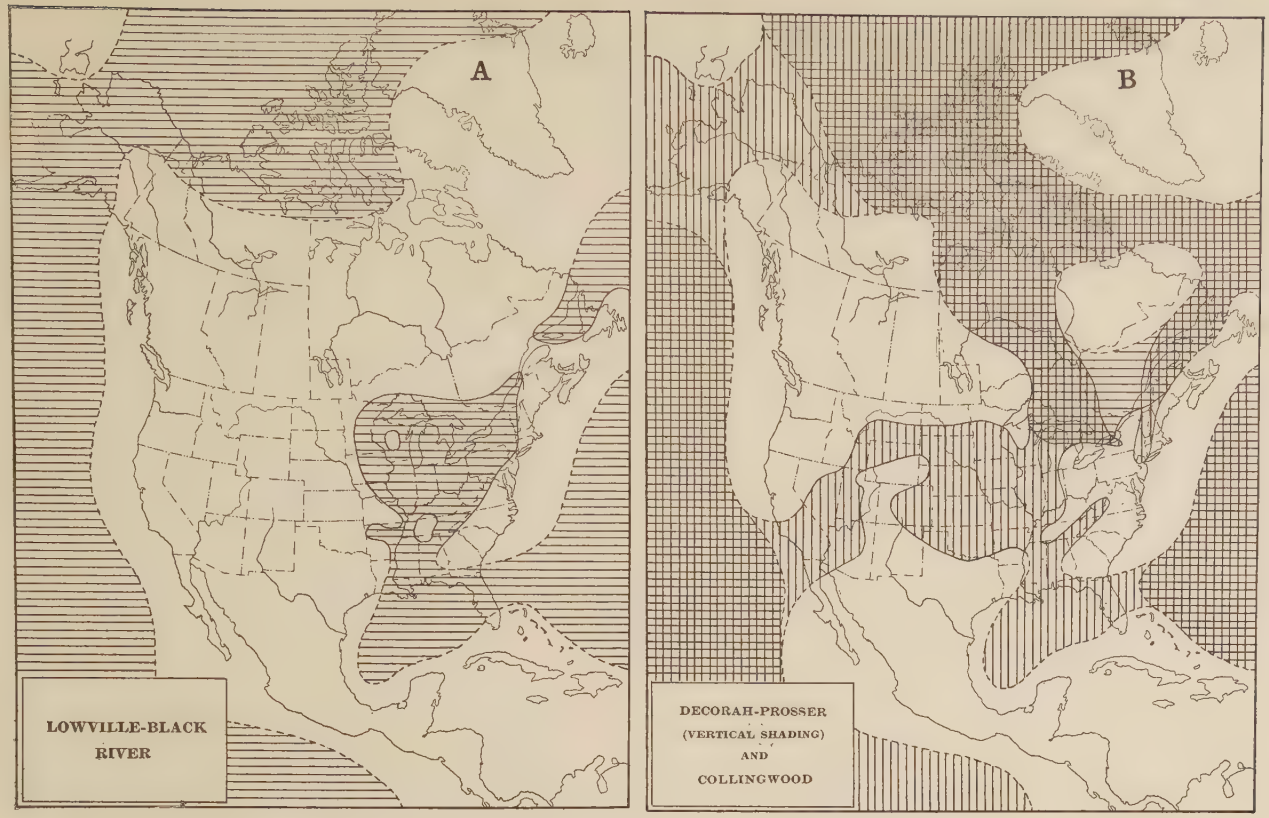


Plate 7. — Middle Ordovician (Champlainian) paleogeography.

the ground by a stalk, see Pl. 6, Fig. 5) are locally common, and contributed largely to the making of limestones. The first true Paleozoic corals appeared here, both cup (Pl. 6, Figs. 3, 4) and compound forms, along with stony hydroids (stromatoporids), and exhibited a tendency to form reefs, but they constituted only small and disconnected colonies. Bivalved crustaceans or ostracods were plentiful and often in large species, and these organisms frequently contributed to the making of limestones.

In Europe the seas of this time were equally prolific in life.

First Vertebrates. — In 1891 Walcott announced the finding of an abundance of fragmentary vertebrate remains in the Ordovician near Canyon City, Colorado, and since then similar remains have been found in the Big Horn Mountains of Wyoming and the Black Hills of South Dakota. These fossils usually occur in a sandstone 6 to 8 feet thick at the base of the Middle Ordovician deposits of the Cordilleran sea. There can be no question that these are the armor bones of fishes of the same type seen often in late Silurian and throughout Devonian time (Ostracoderms). They are described in Chapter XXXVII. From their fragmental nature and their occurrence in sandstones it seems probable that these fishes were inhabitants of fresh waters, and that after death they were drifted by the rivers and broken up before arriving in the marine sediments.

Cincinnatian or Upper Ordovician

Definition. — These formations were first studied in southwestern Ohio and chiefly about Cincinnati, and to the rocks in this region the name was applied by Meek and Worthen in 1865. The Champlainian sea had almost completely vanished from the continent when a new cycle of water movement spread from the Gulf of Mexico northeastward along the western side of Appalachia, northward into the Ottawa basin, and westward into Indiana. This was the sea of Eden and Maysville time (see Pl. 8, Fig. A), a muddier water than that of the two earlier invasions, and it brought back to the interior sea the previous southern faunas that had been changing elsewhere during the emergent interval into other forms. After nearly 500 feet of shales and thin-bedded limestones had been deposited, another flood from the Arctic Ocean arrived, spread its Richmond fauna far and wide over North America and submerged more than 40 per cent of the continent (see Pl. 8, Fig. B).

Life of the Cincinnatian Epoch. — The Cincinnatian faunas were at first very similar to those of the previous epoch, but the Arctic invasion introduced new types of animals which gradually changed

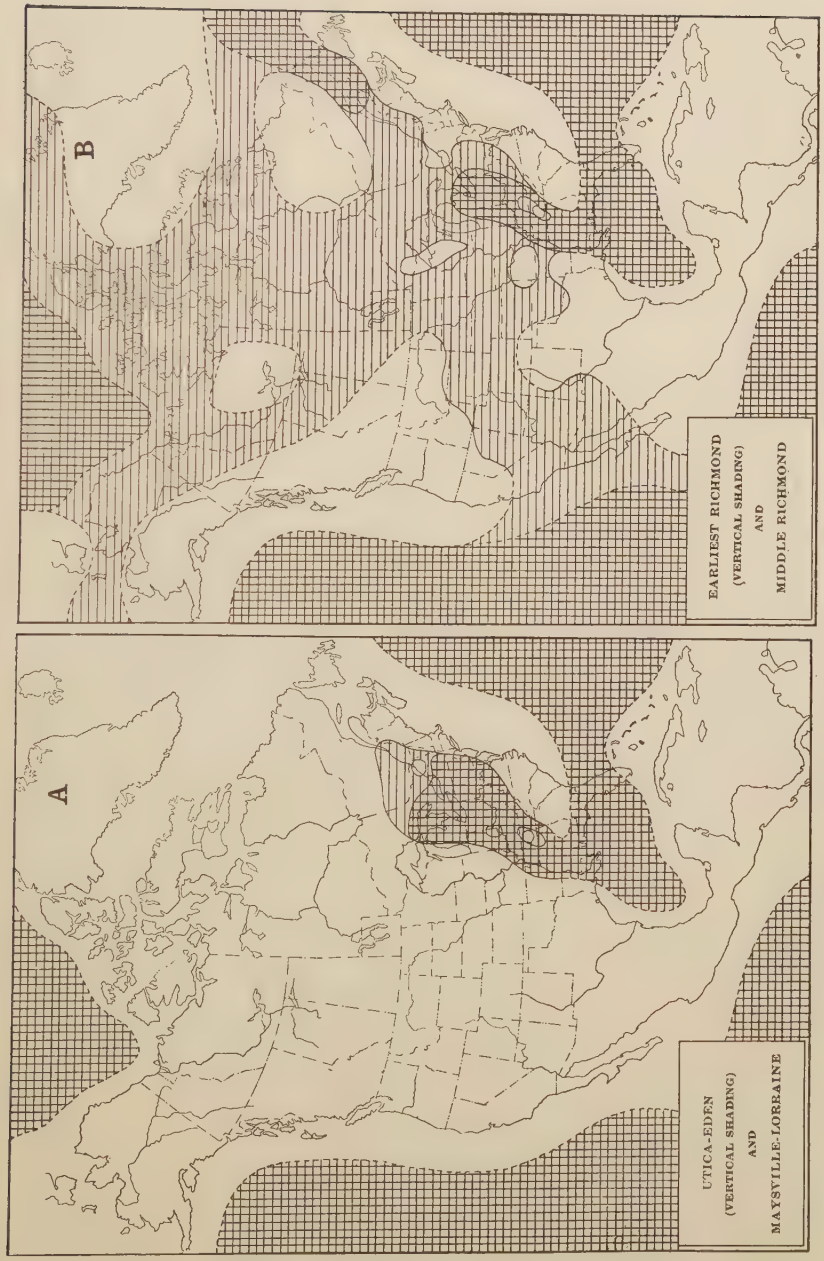


Plate 8. — Upper Ordovician (Cincinnatian) paleogeography.

into others prophetic of Silurian time. These differences are seen more especially among the bryozoans, brachiopods, and corals. However, there is still so marked an Ordovician stage of organic development present in the faunas of the Cincinnatian series as to compel its association with the Champlainian, rather than with the Silurian.

Taconic Disturbance

Cause. — From a study of the paleogeography of Middle and Upper Ordovician time, it is seen that the seas were undergoing much change. This unrest in the hydrosphere was apparently due to movements within the mass of the North American continent, not only depressing and elevating the land but affecting the general level of the strand-line as well. We have seen that the greatest mass of sediments was laid down adjacent to the marginal lands Acadia, Appalachia, and Cascadia, and here, therefore, occurred the greatest depressions of the original land surfaces. In eastern Pennsylvania this maximum sinking was over 15,000 feet during Cambrian and Ordovician time, and it was about the same, or even 1500 feet greater, along the eastern side of Lake Champlain. In the Great Basin area of the Cordilleran sea the sinking of the bottom during the Early Paleozoic was also great, being over 16,000 feet. Such depressions naturally must have set up great stresses that were of gradual accumulation within the mass of the continent, and particularly underneath the areas within and closely adjacent to the geosynclines. Finally, when the stresses attained the breaking point, relief was obtained by readjustments deep within the continent, which also altered the surface topography. This relief was greatest in the northern Appalachian geosyncline, where the Cambrian and Ordovician sediments accumulated, for these strata were raised during the later Ordovician into a mountain range of which the present Green Mountains in western New England and their southern extension, the Taconic Range, are but recently reëlevated western remnants. Dana in 1874 called this disturbance the *Green Mountain Revolution*, but in his text-book of 1895 refers to it as the *Taconic Revolution*.

Cincinnati Uplift. — Long before these eastern mountains became a marked topographic feature, the subsidences within the geosynclines also warped the bottoms of the continental seas and affected their depth, area, and outline. Some of this warping was manifested in the Cincinnati uplift, the southern end of which came first above the sea, for early in Middle Ordovician time (Lowville)

appeared *Nashville island*. This initial uplift then slowly moved northward and reached the area north of Cincinnati before the close of the Trenton. (The axis of this uplift is shown in Fig. 365.) However, the uplift did not remain as yet as a permanent surface feature, for Nashville island was again beneath the sea when the Cincinnati area emerged. With the birth of the Taconic Mountains the Cincinnati uplift attained permanency and became a topographic feature of the subsequent Paleozoic seas.

Metamorphism. — In Vermont, the Cambrian and Ordovician sandstones are now quartzites, the shales are slates, and the limestones are marbles. This change took place when the strata were folded, particularly during the Appalachian Revolution (page 748). Some of the metamorphism, however, may be connected with the rising of the White Mountains of New Hampshire in Devonian time (page 699).

Main Area of Disturbance. — The greater part of Acadia was affected by this disturbance, for the subsequent rocks are seen to rest in most places with an angular unconformity upon the older strata. Such contacts can be seen to advantage at Gaspé, Quebec, where the nearly vertical Ordovician strata have been eroded to a horizontal surface on which repose Lower Devonian limestones. Exactly the same conditions are seen at Becraft Mountain southeast of Hudson, New York, while at Otisville in the same state, but near the New Jersey state line, the angular unconformity between the Middle Ordovician and basal Silurian sandstones (Medina) is not over 15° (see Fig. 397). Unconformities between the Ordovician and later strata are general in Nova Scotia and New Brunswick. We see, therefore, that all the land from the Gulf of St. Lawrence down to at least New Jersey had been thrown into folds, and it is probable that the present Taconic Mountains are but the western member of a series of ranges with similar trends, for it is known that the Silurian, and especially the Lower Devonian, seas entered Acadia in a set of narrow troughs.

Economic Products

Mineral Oil and Gas

Nature of Natural Hydrocarbons. — Natural hydrocarbons, that is, compounds of hydrogen and carbon, are present in all sedimentary rocks of marine origin that are not too much metamorphosed, and while they are also undoubtedly stored in sediments of fresh-water origin, no valuable deposits in such have so far

been found. The greatest amount occurs in a disseminated condition in the shales, especially in the fossiliferous black shales, where oil forms as much as 21 per cent of the rock mass. Even when only 3 per cent of the rock is petroleum it can be extracted by heating the shales and driving off the crude oil, and was so produced many years ago at a cost of 14 cents a gallon. Impure limestones, especially when dark in color, are full of oil, a fact at once noticeable on fracturing them with a hammer, when the odor of petroleum becomes apparent. Even if a rock series 1500 feet thick had but 0.001 of 1 per cent of petroleum, this amount would yield 750,000 barrels to the square mile, an amount nearly equal to the greatest actual production per square mile of any part of the leading Pennsylvania fields (Orton). However, if the material is to be commercially valuable, it must be concentrated by natural agencies into limited underground areas and such invisible reservoirs must be discovered by the driller, but these valuable accumulations are not of common occurrence. The natural hydrocarbons occur in the sedimentaries in all conditions from natural gas through light oil and heavy oil into asphalt. For the distribution of the oil and gas fields in the United States see Fig. 383.

Original Source of Hydrocarbons. — The hydrocarbons in the main result from bacterial decomposition of organic material, and chiefly from animal remains undergoing reduction on the sea floor. That they are of organic origin is proved by the fact that they have the same optical properties as animal oils. Microscopic globules of oil result from the bacterial change and have a very decided affinity for tiny flakes of mud suspended in the water. When there is much rapid organic destruction going on in muddy waters of little or no circulation, there results a more or less decidedly petroliferous shale, or a dark impure limestone, but in clear water and in agitated seas most of the hydrocarbons escape into the air.

Storage of Oil and Gas in Nature. — Oil and gas are segregated into reservoirs or " pools " in porous rocks which in most cases are sandstones or conglomerates, and more rarely crystalline dolomites (see Fig. 421). This concentration seems to be due in most cases to percolating waters that are now, or were formerly, within the sediments and which, by their movements, drive the disseminated oil out of the rock. The latter, being lighter, gathers at the top of the water, and if this is under hydrostatic pressure the compressed gases coming from the oil are driven to higher levels until stopped by a thick shale stratum, for shales are practically impervious to water, oil, and gas. When the rocks are devoid of water, in which

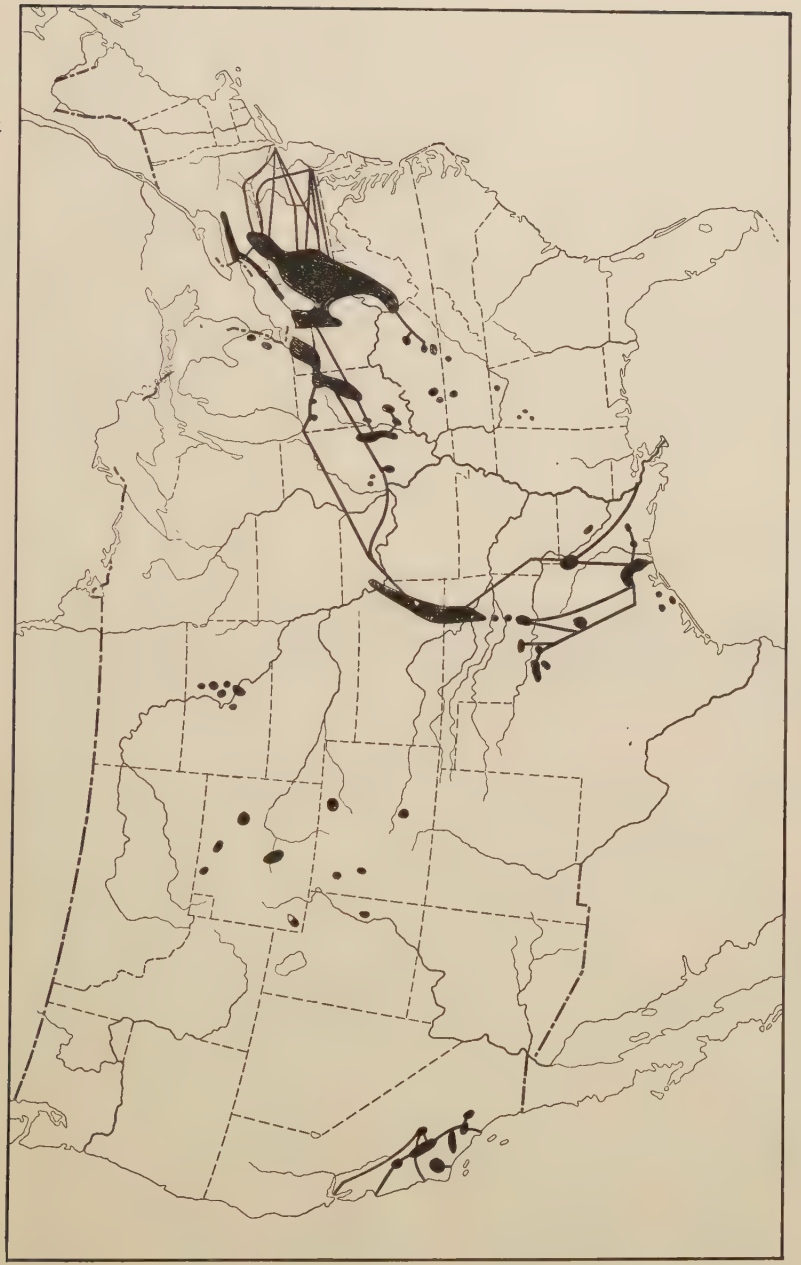


Fig. 383. — Map showing in generalized form the main oil and gas fields and pipe-lines in the United States. Redrawn from a large and detailed map published by the U. S. Geological Survey.

case they are said to be " dry," the gas separates from the heavier oil and rises to higher levels of the rock beneath the shale cover, while the oil gravitates down the dipping slopes of the strata to lower levels and segregates in the more porous areas, where oil " pools " are formed. The pools in dry strata are more irregular in distribution than those in wet formations. When a large quantity has concentrated there seems to be a tendency for the pools to seal themselves at the top, and, if more and more oil and gas are added from below, the " rock pressure " rises above the hydraulic pressure or " head " produced by the water of circulation. Lower " rock pressures " are the rule, from 350 to 500 pounds to the square inch, but they are known up to 1525 pounds to the square inch (in gas wells). Hydrocarbons may also be driven to higher levels by the heat of subterranean bodies of intrusive igneous rock, or by chemical alterations within the strata, but such fields are the exception.

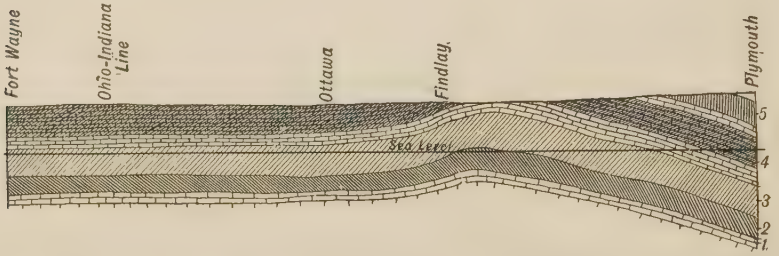


Fig. 384. — Geologic section through Ohio-Indiana oil and gas fields. The arch is the Cincinnati uplift. 1, Trenton limestone, the oil and gas horizon; 2, impervious shales of the Ordovician (Utica and Eden); 3, Cincinnatian; 4, Silurian limestones and dolomites; 5, Devonian limestone and shales. After Orton, U. S. Geol. Surv.

Geologic Structure of Oil and Gas Areas. — Oil and gas are usually found in the flattened tops of depressed geologic arches and down the slopes of anticlines where the dip of the strata is arrested so as to form shelves or terraces (the " terrace structure " of oil experts), but there is always above the productive zones an impervious and usually a thick shale cover. Broadly stated, the thicker the shale formation, the more impervious the cover, and the deeper the storage bed, the richer the gas or oil field (Fig. 384).

Trenton Oil and Gas of Ohio. — The oil and gas of Ohio and Indiana are stored in the upper 20 to 30 feet of the Trenton dolomite, in places where it is highly crystalline and therefore very porous, and at depths of from 1100 to 2200 feet below ground (Fig. 384). The black to brown Utica shale, hundreds of feet thick, forms the impervious cover. Below the oil and gas there is always

highly saline water. The oil and gas fields are connected in the main with the "terrace structure" of the Cincinnati uplift and are situated under its northern end, and under the short northeasterly trending arch known as the Lima spur of Ohio and the broader northwesterly trending arch known as the Wabash spur of Indiana. The once famous Karg gas well of Findlay, Ohio, stood on the edge of a rapid descent of the Trenton dolomite; and only a thousand feet west of it, where the top of this formation lay 120 feet lower, the adjacent well yielded petroleum.

Discovery of Oil and Gas in Ohio. — As far back as 1836 natural gas was known to escape freely from the ground in the vicinity of Findlay, Ohio, and for a long time a few very shallow wells were covered to collect the gas for domestic use, but only Doctor Oesterlin, after 1862, suspected that great reservoirs of it were stored deep in the strata. It was not until 1883, however, that he finally succeeded in forming a company to drive the "Pioneer Well," which yielded Trenton gas at a depth of 1092 feet beneath the surface. *This has been regarded as one of the most important discoveries in Economic Geology of the past century.* The daily flow of gas from this well was 250,000 cubic feet. Before the close of 1886 three great gas wells were found: the Karg well, giving 14,000,000 cubic feet of gas per day; the Simons well, 12,000,000; and the Van Buren well, exceeding both with 15,000,000. Artesian oil wells were also soon found yielding hundreds of barrels per day, and exceptional ones with a daily flow of 1000 and even 5000 barrels per day. Ohio then became alive to its underground wealth and an oil and gas excitement spread throughout the state. The fever spread to Indiana, and this state became an even greater gas producer, with a daily yield in 1890 of 780,000,000 cubic feet. Entire industries, such as that of glass making, moved at this time to central Indiana because of the cheapness and easy adaptation of this fuel.

Even though it was soon learned that wells lasted at most but several years and then declined rapidly to extinction, tremendous waste occurred. Nature's great wealth of long accumulation was soon dissipated, though the period of Indiana and Ohio's gas prosperity would have lasted several times as long under wise protection against wastage. I. C. White has stated that the gas and oil wasted in the United States during 1908 was roughly equivalent in fuel to the heat yielded by one billion bushels of coal!

Annual Yield of Oil and Gas in the United States. — The yield of petroleum in 1913 in this country was 248,000,000 barrels, valued at $237,000,000. The value of natural gas for the same year was $88,000,000. Eighteen states have yielded since 1859, when oil was "struck" in Pennsylvania, 3,000,000,000 barrels of petroleum, valued at $2,575,000,000.

Other Economic Products

Limestone, Marble, and Cement. — Because of the wide surficial distribution of the Ordovician limestones they are much quarried for foundation structures, road metal, flux for the reduction of iron ores, and especially for the lime used in mortar, whitewash, and fertilizer for farm land. In the Appalachian valley they

are also much used in the making of Portland cement. In Vermont there are immense quarries in the Lower Ordovician from which is obtained most of the American Carrara, or white and clouded marble. In eastern Tennessee some of the Middle Ordovician fossiliferous limestone is mottled pinkish to deep red in color and is used for decorative and interior purposes.

In the United States in 1913 there were 113 plants making Portland cement. During this year they made over 15,000,000 long tons, valued at $92,000,000.

Lead and zinc, mainly in the form of sulphides and carbonates, have been mined for more than a century and in considerable quantity from the Middle Ordovician dolomites of eastern Iowa, southern Wisconsin and northern Illinois; the formation from which they come is known to geologists as the Galena formation, and is of the same age as the Trenton of New York. The ores occur in solution cavities, in crevices, or as replacements of the limestone. Some lead is also yielded by the Upper Cambrian of the Ozark region of Missouri and Arkansas.

Calcium phosphate, valuable as a fertilizer, is obtained in central Tennessee, where the limestones are rich in the tiny gastropod shells (*Cyclora*) mentioned on page 619.

CHAPTER XXXV

ANIMALS WITH RADIAL SYMMETRY

Radial and Bilateral Animals. — Among the lowly organized invertebrates there is a vast variety in which the outer form and the arrangement of the organs are seemingly not bilaterally planned, as in most animals. In this group, instead of the halves on each side of an imaginary median line having the same structure but arranged in an opposing way, the two parts being left- and right-sided, the symmetry is radial, the parts radiating from the central mouth and body sac. The naturalists of the early part of the nineteenth century grouped all animals with such symmetry under the name *Radiata*. Later it became apparent that their radiate structure was often only superficial, and that most of them when young were built on the bilateral plan; in other words, that radial symmetry in mature animals did not necessarily indicate blood-relationship. This classification of animals based on superficial resemblances naturally had to be given up, but nevertheless the description "animals with radial symmetry" is applicable in a broad way to many invertebrates and helps the beginner in Historical Geology to understand their fundamental adult structure. The radiate form is probably largely due to the sedentary and sluggish habits of the animals which possess it, and it is all the more readily brought about because of the absence of a definite head region.

Types of Radiate Animals. — Animals with radial symmetry are now classified into two wholly independent divisions. The more simply formed or primitive one is the stock (phylum) *Cnidaria*, or *Cœlenterata* (cœlenterates), the latter name implying that the animals have but one internal cavity which serves both as a body cavity (cœlome) and as a digestive cavity or sac (enteron). All higher animals, on the contrary, have two cavities, a true body one which may contain the internal organs, such as the heart and lungs, and within this another independent digestive cavity, such as the stomach or intestine. These higher animals are known as cœlomates. The cœlenterates are, as a rule, very simple animals in which appear the beginnings of definite organs. In their variety

they seem nearly to exhaust the possibilities of radial symmetry, and many are very flower-like. They have, therefore, also been called zoöphytes (plant-animals), and in their budded colonies afford interesting illustrations of coöperation and division of labor. Practically all of them live in the sea. In the Cnidaria the secretion of an external skeleton composed of carbonate of lime is not the rule, although it is marked in some stocks, as, for instance, among the corals.

The second division is the phylum *Echinodermata*, including animals that generally have marked superficial radial symmetry, but as they have the true body cavity, and are, therefore, cœlomates, they cannot be grouped under the old term Radiata. The Echinodermata and Cœlenterata as differentiated above are brought together in this chapter for easy reference. There is in the former a more decided tendency to form calcareous skeletons. In the very young or larval stage these animals are distinctly bilaterally symmetrical, and are placed higher in the scale of animal life than the Cnidaria. Echinodermata are exclusively marine and are of great diversity of external form.

The following table presents briefly the kinds of animals having a radiate structure:

Phylum **Cnidaria.** Marine animals that are free or attached to the ground. They live as individuals or are combined into colonies, and they may have a skeleton that is either horny or of carbonate of lime.
- Class **Hydrozoa** or hydroids. Simplest and least known Cnidaria.
  - **Graptolites.** Ancient hydroids with horny skeletons.
- Class **Anthozoa** or coral animals.
  - **Sea anemones.** Individual coral animals without skeletons.
  - **Stony corals.** Corals with skeletons of carbonate of lime.
    - **Archæocyathidæ.** Primitive individual Cambrian corals.
    - **Tabulata.** Paleozoic colonial corals without true septa.
    - **Tetracoralla.** Paleozoic individual and colonial corals with septa.
    - **Hexacoralla.** Post-Paleozoic corals with septa.

Phylum **Echinodermata.** Marine animals usually with an external skeleton of carbonate of lime, made up of many pieces.
- Class **Stelleroidea.** Starfishes. Free animals.
- Class **Echinoidea.** Sea-urchins. Free animals.
- Class **Crinoidea.** Attached feather-stars.
- Class **Blastoidea.** Attached nut-like animals or pentremites.

Corals and Coral-like Animals

(*Phylum Cnidaria*)

General Description. — In the living world there is a vast group of diverse, radially symmetrical, marine animals that the zoölogist speaks of as Cnidaria (from the Greek for *nettle*), because the great

majority of them have the power of stinging. This stinging is done by a multitude of very minute threads, each one of which is shot out of a cell buried in the skin and enters any soft body that comes into contact with the animals (Fig. 385). More of the stinging cells may be connected with the internal cavity, where they are a part of long filaments attached to the inner edges of the mesenteries or the vertical partitions (septa).

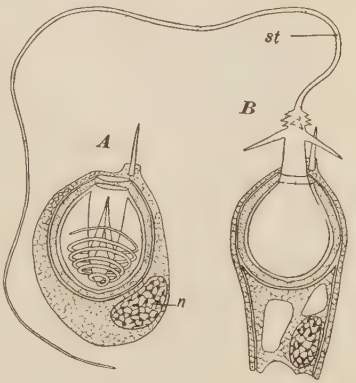


Fig. 385. — Stinging or nettle cells of *Hydra*. Greatly enlarged. After Schneider. *A*, undischarged cell, note trigger hair. *B*, discharged cell with the poisonous thread (*st*) released. *n*, nucleus.

In general, it may be said that Cnidaria are very primitive animals whose body is a sac with the closed end attached and the other free, the widely distensible opening being the mouth. Into it is passed the food, which is digested in a more or less simply constructed cavity of the sac, and through the same opening is ejected any indigestible remainder. They feed, as a rule, on the smaller animals, but when the individuals, or polyps, as they are called, are minute, their food consists of microscopic animals or plants. Around the mouth are situated radially a number of hollow, finger-like tentacles and much of this tentacular end, or even the entire outer surface, is covered with innumerable stinging cells.

The microscopic stinging cells have a flask-shaped cavity containing a long, delicate, coiled thread immersed in a more or less poisonous fluid (see Fig. 385). On the outside of the cell there is a minute trigger-hair, a very delicate sensory organ, which, when touched, causes the cell to burst and thrust out violently the long thread, thus serving as an organ of defense against enemies and as a means of capturing small animals for food.

Jellyfish or Medusæ. — There are two widely different kinds of Cnidaria individuals: the attached polyps just described, and the free individuals or medusæ, widely known as swimming-bells or jellyfish (Fig. 386 *A* and *B*). The medusæ are very soft, disc- or bell-shaped animals with the mouth and stomach hanging from the under side of the bell, while around its edge are the stinging tentacles. As the medusæ are from 95 to 99 per cent water they are very seldom preserved as fossils and therefore have little significance in Historical Geology and need not be further considered.

Divisions of Coral-like Animals. — There are many types of Cnidaria, not all of which have hard parts, but in this connection only the more important forms need be studied, those that have skeletons either of chitinous (nitrogenous) or calcareous material. The Cnidaria are divided into two classes, the Hydrozoa and the Anthozoa.

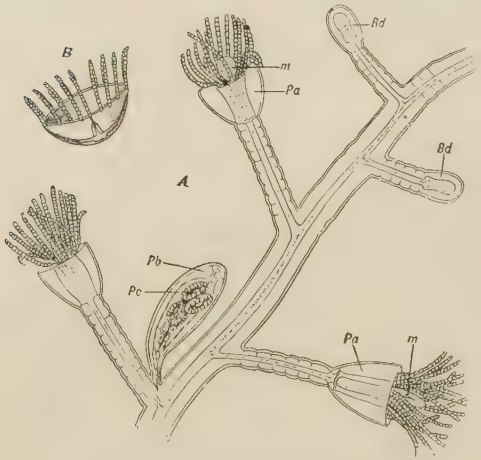


Fig. 386. — Hydroids. *A*, small part of an unsexed, attached hydroid colony (*Obelia*). Much enlarged. *B*, sexed and free medusa stage, with tentacles arranged around margin of umbrella. About nat. size. *Bd*, buds developing into polyps; *m*, mouth; *Pa*, feeding polyps with tentacles extended; *Pb*, reproductive polyp developing medusæ (*Pc*).

Hydrozoa

Hydrozoa or hydroids (named after the nine-headed dragon of Greek mythology, because of the many polyps) usually have chitinous external skeletons and a digestive cavity or cœlenteron which is undivided and relatively simple in that the walls of the sac are not folded or ridged. The mouth is rounded. The polyps live singly or are united into colonies with the members connected with one another. In the colonial forms there is often a division of labor, some being nutritive members, others reproductive members, and so on. The hydroids of most interest in Geology are the extinct graptolites.

Graptolites (from a Greek word meaning *to write*, because the fossils resemble writing) were linearly arranged colonial hydroids with thin chitinous tubular buds, one end of which was fastened to a rod-like axis (see Fig. 387 *A* and Pl. 4). The polyps were arranged in a single linear series (monograptids, Pl. 4, Fig. 6) or there were two series back to back against the axis (twin-graptids, Fig. 7) or even four series with the rod in the center (leaf-like graptids, Pl. 4, Figs. 1–3). A variable number of such colonies were fastened by rods (*virgulæ*) to a float or swimming bell from which they hung; in this way they were freely suspended in the water and drifted along with the sea currents. These were the true or free graptolites, the forms that have much significance in Stratigraphy because the species were common only for a limited time and were scattered widely by the oceanic currents.

Another group of these animals, known as the *dendroid* or net-like graptolites, were of very different habit, being attached either to seaweed or to the sea bottom (see Fig. 387 *B*). These polyps did not have the axial rod but were arranged on flexible, more or less

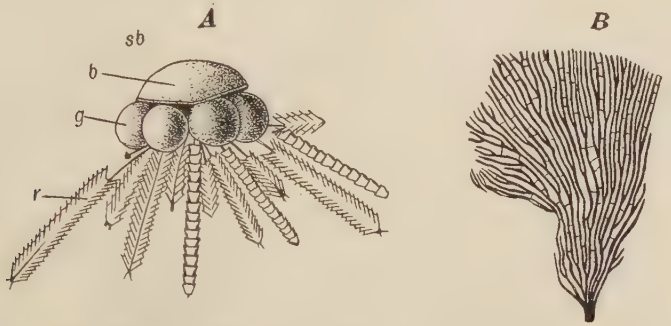


Fig. 387. — Graptolites or Paleozoic hydroids. *A*, restored colony of floating type (*Diplograptus pristis*). Somewhat enlarged. After Ruedemann. *b*, swimming bell; *g*, gonangia or brooding organs; *r*, a branch (rhabdosome) of many polyps in two ranges. *B*, dendroid type of anchored graptolites (*Dictyonema crassi-basale*); the polyps are microscopic and like those in *A*. After Bassler.

irregular branches united to one another by cross-bars. The colonies grew fan-shaped or irregularly funnel-shaped. As a rule, all graptolite fossils are black and they are most frequently met with in black shales.

The dendroid graptolites appeared in the Ordovician and persisted into the early Mississippian but were most abundant in the Ordovician and Silurian. The true graptolites were practically restricted to the two last named periods, while the monograptids were especially abundant in, and characteristic of, the Silurian.

Fig. 388. — A sea anemone, with tufts of tentacles about central mouth. After Emerton.

Anthozoa

The Anthozoa or flower animals include the sea anemones and corals. They are attached polyps whose internal cavity has hanging down in it a rudimentary, tubular, digestive gullet, opening upward into an elongated mouth and below into the true digestive cavity or *cœlenteron* (see Fig. 389). The wall of the latter is not simple as in the Hydrozoa but has a number of longitudinal folds or ingrowths of the body wall projecting more or less deeply into the cavity. When one of these polyps is cut transversely the folds

or partitions are seen as radii, for which reason they are also known as ray animals (Fig. 389). When a hard supporting skeleton or stony part, known as the corallum, is present, as is most often the case, it is usually made of calcium carbonate (see page 171), is nearly always secreted by the outer layer of the soft body, and has its exact form. Therefore the skeletons of corals have an internal radiate or partitioned structure never seen in the Hydrozoa, and it is only this lime skeleton which is preserved in the fossils. The polyps either live singly and are then cylindrical or conical in shape, or more commonly form colonies by the budding of closely adjoining individuals.

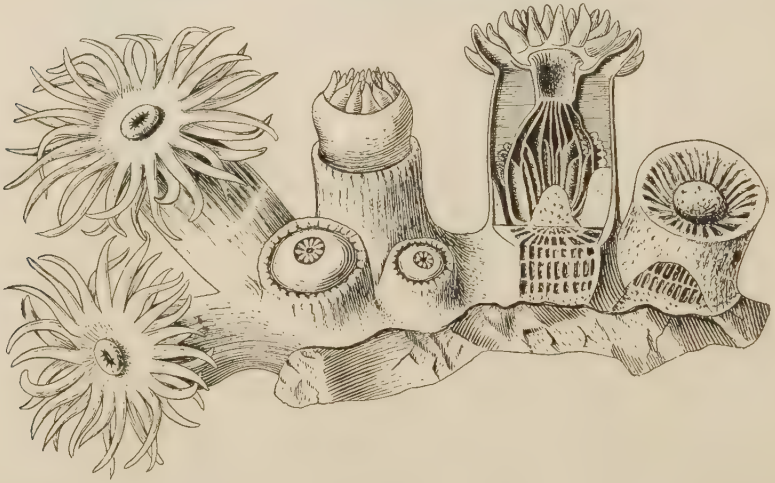


Fig. 389. — Colony of living stony corals, with two individuals fully expanded and feeding, and three individuals retracted and resting. On the extreme right is seen the skeleton of an individual and beside it an individual cut through the center to show the relation of the soft parts to the skeleton, the mouth opening into the gullet, and the large digestive cavity with its many mesenteries. After Pfurtscheller, from Boas's *Lehrbuch der Zoologie*.

They are often brilliantly colored. The polyps known as sea anemones have no skeleton (Fig. 388), but the corals, as a rule, secrete one of calcium carbonate and are therefore called "stony corals," though a few have horny black skeletons and are known as "black corals." The animals that build the stony skeletons are usually very small (under one fourth of an inch), though some kinds attain a diameter of an inch or more, and the sea anemones may even exceed 8 inches. The colonial skeletons may be of any size up to 15 feet across and in height.

Stony Corals. — Cup corals, which are the calcareous bases of single polyps, are of very frequent occurrence in Paleozoic rocks.

They multiply by sexual reproduction and not by budding, as is the case in compound forms. Cup corals are usually conical and more or less curved, with variably deep cups divided into many shallow compartments by radially arranged partitions called septa (see Fig. 390). These septa originate in the outer wall and are of variable length, the several lengths being disposed in a regular manner; only a part of them, the primary septa as a rule, meet in the center, where they often form a simple or twisted column, the columella. The compound corals have about the same general structure as the single polyps, but when closely crowded the corallites take on a prismatic form (see Fig. 391). They may also be circular in outline and then the spaces between the individuals are filled with a loose structure.

Fig. 390. — Paleozoic cup tetracorals. *A*, common Devonian form (*Heliophyllum halli*), with ornate septa. *B*, Silurian form (*Zaphrentis umbonata*), with deep cup, many septa, and a fossula. *C*, Devonian species (*Amplexus yandelli*) sectioned to show tabulæ. After Rominger.

The types of coral structures most often seen fossil are the following:

Archæocyathidæ or archeocyathids (primal cup corals). — These are the most ancient and the simplest corals known and are restricted to the Lower Cambrian (see Pl. 1, Figs. 5, 6). All are single polyps, the corallum being a more or less long cone, sometimes reaching 11 inches in length, nearly straight, and with one end tapering to the point of attachment. Commonly these corals are, however, under 3 inches in length. The outer wall may be thick and porous or with worm-like canals, or there may be two thin walls united by longitudinal, radially arranged septa. The basal por-

tion of the corallum is also more or less thickened by vesicular partitions. The living chamber is very large and deep, sometimes reaching almost to the bottom of the corallum, and is devoid of septa throughout, a condition of primitiveness seen in no other corals. Furthermore, the walls in most forms are regularly perforated by comparatively large pores arranged in longitudinal series, another character not seen in other corals and one whose purpose is not yet understood. For their wide distribution, see the chapter on Cambrian time (XXXI).

Tabulata or tabulate corals (*tabula* means *bottom* and has reference to the many transverse partitions found in the tubes). — These specialized Paleozoic corals always grow in colonial form, and, as a rule, the individual polyps are very small or even minute transversely, but longitudinally they build more or less long tubes

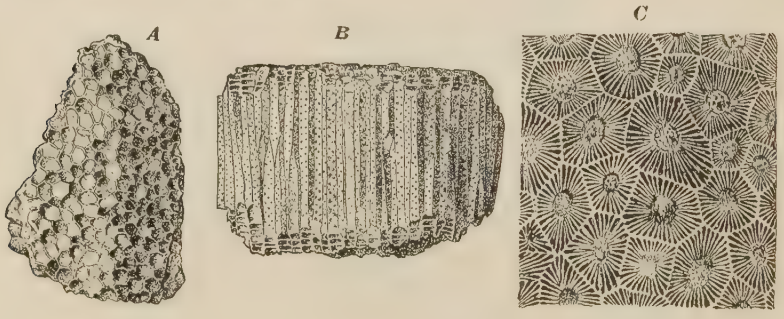


Fig. 391. — Compound Devonian corals. *A*, tabulate or honeycomb coral (*Favosites polymorphus*). *B*, same, from the side, to show transverse partitions (tabulæ) and small mural pores. *C*, transverse section through a tetracoral (*Cyathophyllum rugosum*), showing close union of individuals, and radial septa.

that are abundantly partitioned by tabulæ as the animals grow upward (see Fig. 391 *A* and *B*). The polyps may be loose in growth when the individual corallites are round or oval in outline, but more often the tubes are tightly appressed to one another and the corallites uniformly prismatic. There are no radial septa and when such appear to be present they are seen to be a series of short spines arranged in longitudinal rows (incipient septa, as it were), or the spines may be irregularly disposed. The walls of the corallites are thin and perforated by large pores, the mural or wall pores (see Fig. 391 *B*), which represent failures at budding for the reason that almost no space is present for the vast majority of the possible buds to grow into individuals.

The tabulate corals appeared in the Middle Ordovician and had their greatest development in the Silurian and Devonian.

The chain coral (*Halysites*, Pl. 9, Fig. 1) was characteristic of the Silurian and Ordovician, while the honeycomb corals (*Favosites*, Fig. 391 *A* and *B*) were great reef makers in the Silurian and Devonian, where some of the colonies had a diameter of 4 feet. The organ-pipe-like coral (*Syringopora*, Pl. 16, Fig. 8) was common throughout the Silurian and most of the later Paleozoic time.

Tetracoralla or tetracorals (corals with the septa arranged in four quadrants). — Throughout the Paleozoic from Middle Ordovician time, and more especially beginning with the Silurian, the tetracorals are common fossils (see Figs. 390 and 391 *C*). Cup corals were very common in the Middle Paleozoic and were more numerous, in greater variety, and of larger size (up to 2 feet long) than those of subsequent times. Compound tetracorals were also abundant, and, with the cup corals, were of wide distribution, being especially common as reef makers in the Silurian and Devonian. They were rare in the Pennsylvanian and passed out of existence with the Permian.

In the cup tetracorals the bundling of the septa is usually readily seen, and with their smooth or somewhat wrinkled exterior covering (*epitheca*) extending from the base to the edge of the cup, they are easily distinguished from other kinds. The compound tetracorals are usually not so easily separated from the Hexacoralla (six-rayed corals), because the tetramerism or division into four parts is much or wholly obscured, but, as a rule, it is seen that the polyps are larger while the radial septa are more numerous or at least thinner, straighter, and simpler. Some of these compound tetracorals attain the size of modern colonies and have been seen as large as 12 feet across.

Hexacoralla or hexacorals were the common kinds after Paleozoic time and are the main reef builders of the present oceans. The name has reference to the fact that the young polyps start with six primary septa and all subsequent cycles of partitions are regularly introduced between the previous ones. There is, therefore, a regular radial arrangement of the septa and they are never bundled into quadrants as in the Tetracoralla, and the single polyps are also not so decidedly cup- or funnel-shaped. In the compound forms the animals are apt to be small, often very small, as in the staghorn corals, while the corallites are not, as a rule, so distinctly walled from one another as are the older corals. The walls often also appear to be thick, and in many forms the individuals are compressed and seem to merge irregularly into one another, suggesting the convolutions of a mammal brain, hence the name brain-corals, which is sometimes applied to them.

Habitats of Living Corals. — Hexacorals live in all oceans from sea-level down to 11,000 feet, but are particularly common in clear tropical waters and in depths of less than 240 feet. In the deeper, darker, and colder waters the single polyps predominate, while on the reefs where the sunlight is strong the compound corals are most prolific. There are five times as many kinds of hexacorals in waters not over 150 feet deep as there are between this depth and 240 feet, the maximum depth to which any reef species extends. Between 600 and 2400 feet there is another coral zone, usually of small single polyps or of delicate, branching, compound forms. Beyond the latter depth corals are few in number and variety and those that do exist are small and extremely fragile. Off the eastern coast of North America between Cape Hatteras and Newfoundland there are known to be living fourteen species of corals, several of which go below 6000 feet (Verrill). Hemispheric corals are known to attain to 15 feet in diameter, while staghorn colonies are reported growing to heights of 15 feet.

In regard to the temperature, strictly reef-building corals flourish only between 68° and 78° F., but will continue to live even at 85° F. The deeper coral zone has a far lower temperature, one between 40° and 50° F., and the deep-sea species may live in water as cold as 32° F. In regard to the nature of coral reefs and the places of their growth, see page 171 and the following pages. A view of a living coral reef is shown in Fig. 145.

Spiny-skinned Sea Animals
(*Phylum Echinodermata*)

General Description. — In the seas and oceans there is a great variety of radiate animals called echinoderms, which means *spiny skin*, a name given because their outer surface is usually more or less studded with parts composed of carbonate of lime in the form of spines and plates. These hard pieces may consist of small particles loosely dispersed in the skin, or occur in the form of spines that make a loose or open mesh, or entirely encase the soft parts in a firm skeleton, a mosaic of closely adjoining plates that are either plain or studded on their outer surface with more or less long spines.

The parts of the body are usually arranged on the plan of five divisions, five radii and the same number of spaces between them — the interradii — being characteristic of the echinoderms. These parts are best seen in the starfishes; while they are present in nearly all Echinodermata, they are at times much obscured. Again,

the five primary rays may divide or fork repeatedly. Along each radius are usually two or more rows of soft, tube-like processes, terminating in sucking disks; these are the *tube-feet*, which constitute the chief organ of locomotion in starfishes. However, these organs may be completely modified into feelers or respiratory organs in forms that do not crawl about. The tube-feet are connected with the *water-vascular* or *ambulacral system*, a system of tubes peculiar to this phylum, consisting of a circular canal extending around the inner side of the centrally situated mouth, from which branch five canals that run along the center of the arms or radii, these five giving off, in turn, numerous lateral branches which connect with the tube-feet. The sea water has access to this system of canals on the dorsal or upper side of the starfish through a large, porous, sieve-like plate called the *madreporic plate*, and the animals can force the water into the tube-feet and so elongate them into action. Coming in contact with some foreign object, the feet attach themselves by their sucker-like ends and then, by contraction, slowly pull the animal along.

Divisions of Echinodermata. — The Echinodermata are divided into two main classes on the basis of their leading a free or sedentary life. The free forms having fossil representation are the starfishes (including the brittle stars) and the echinids. The sedentary or attached, stalked kinds are the crinids and blastids, nearly all of which are characterized by having a more or less long jointed stalk by which they are, as a rule, fixed to the ground. In the free forms, the mouth is on the under or ventral side, and it is on this side that they crawl about in search of food. The stalked forms, however, are turned over and have the mouth and the ventral surface upward, while from the center of the back or dorsal side originates the stalk, which is usually fastened to the sea bottom. All of the forms that are attached or sessile feed on microscopic food taken out of the circulating sea water. Most of the Echinodermata have the power to reproduce parts bitten off by predatory animals, and a starfish may be torn into several pieces and each piece, under favorable conditions, will regrow the lost parts, because an arm retaining a part of the disk has all the essential organs of an entire starfish.

Free Echinodermata or Asterozoa

Starfishes or Stelleroidea. — The great majority of these animals have a more or less large disc from which radiate at least five arms. The latter may be long and slender or indistinct be-

cause of the enlarged interradial areas. In the latter case, the dorsal side appears as if only the disc were present, but if viewed from the ventral side the five radii, or ambulacral furrows, are seen extending from the central mouth to the tips of the arms. The skeleton buried in the skin is more or less of a mesh of spines, except along the ambulacral furrows, where it consists of distinct and closely adjoining plates perforated by the tube-feet. Because of this loose nature of the skeleton, the parts are easily separated when the animal is dead and for this reason are rarely preserved in their entirety.

Starfishes appeared in the Ordovician, but entire specimens are among the rarest of fossils in Paleozoic rocks (see Fig. 419, an exception to the rule). In the Mesozoic, whole ones are met with more often, but at no time are they of significance in Historical Geology. As limestone makers their dismembered skeletons are of more importance.

Brittle stars (or Ophiuroidea) occur as fossils oftener than the true starfishes but their geologic significance is also small.

Echinids or Echinoidea. — These are the sea-urchins, sand-dollars, and heart-urchins, and, as a rule, are extremely spiny, many

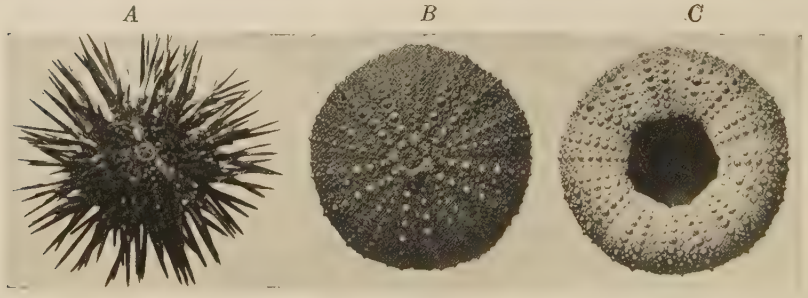


Fig. 392. — Skeletons of two kinds of living sea-urchins (Regularia). *A*, purple sea-urchin (*Arbacia punctulata*), with all its spines, from dorsal side. × ½. *B*, *C*, common sea-urchin (*Strongylocentrotus dröbachiensis*) stripped of its spines to show corona from dorsal and ventral (mouth) sides. × ½. After Coe, Connecticut Geol. Surv.

of the spines being movable on ball-and-socket joints. In general form, the echinids are dome-shaped, the wall of the dome being made up in living forms of twenty columns of closely adjoining plates arranged in pairs (see Fig. 392 *B* and *C*). Five pairs of these are the *ambulacral columns* which are perforated by tube-feet, and alternate with five other pairs which are not perforated, the *interambulacral columns*. The mouth is on the lower or flatter side and is often provided with a powerful jaw of very complicated structure, first described by Aristotle and compared by him

to a Greek lantern, hence it is now referred to as "Aristotle's lantern." At the top of the dome or corona is the anal opening, around which are arranged ten plates in one or two circles. The five large plates of the inner ring are called the *genitals* because each is pierced by an opening, the terminus of the genital organs. The five smaller plates of the outer ring, situated at the termini of the five pairs of ambulacral columns, are known as the *oculars* because in them are located the so-called eyes (see Fig. 394 *B*, but here the plates are arranged in a single ring).

The echinids just described are called *regular echinids* because they are the normally constructed forms, but in the seas of to-day there are many others whose structure is less normal and which

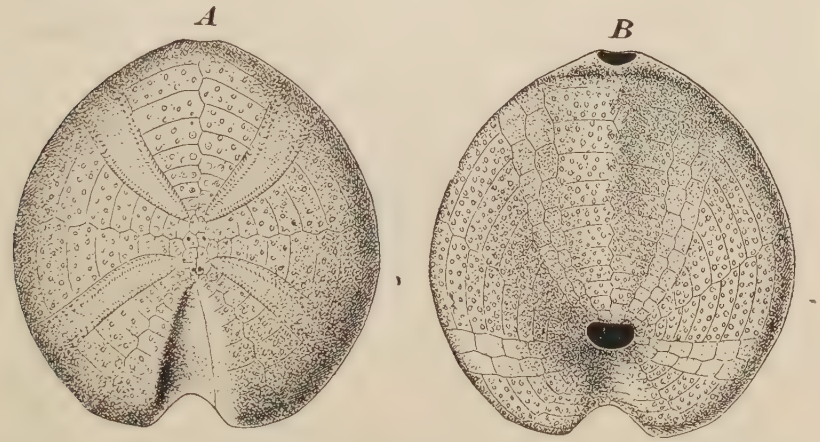


Fig. 393. — Fossil heart-urchins (*Cardiaster cinctus*) from the Cretaceous of New Jersey (Irregularia). *A*, from dorsal, and *B*, from ventral side. After W. B. Clark, U. S. Geol. Surv.

are known as *irregular echinids*. Their irregularity consists in that the anal aperture is not at the top of the dome but on the posterior ventral surface (see Fig. 393). Further, they are not circular in outline but are somewhat elongate, often lobate and heart-shaped, and hence are called heart-urchins. The sand-dollars are also of the irregular type. The spines in these forms are very short and slender and usually there is no lantern-like jaw.

The echinids described above are practically unknown in the Paleozoic rocks, but, appearing in the earliest Mesozoic, become more and more varied and are of much importance in Historical Geology. This is particularly true for Europe, where the Mesozoic strata are at times crowded with them, but in America they are always rare except in the Comanchian beds of Alabama, Texas,

and Mexico. The regular echinids were not rare in the Triassic, but the irregular forms did not arise until late Jurassic time and were not common until the Comanchian. Both of these stocks are common in the present seas, with about 500 species. About 2500 fossil forms are known.

Paleozoic Echinids. — The Paleozoic echinids differ from the later ones in having as many as seventy-five columns of plates in the dome (corona) (see Fig. 394). Here the ambulacral areas have from two to twelve rows and the interambulacrals from three to eleven. Further, the plates usually overlap like the shingles on a roof. These forms appeared in the Devonian but were not common until the Mississippian, when the melon echinids (*Melonechinus*) were characteristic. In the Pennsylvanian and Permian

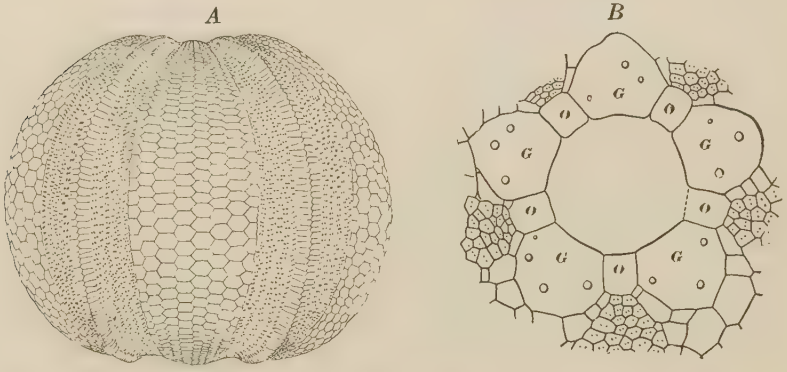


Fig. 394. — Paleozoic echinid (*Melonechinus multiporus*) from St. Louis, Missouri. Note the many columns of ambulacral (perforate) and interambulacral (imperforate) plates. *A*, from the side. After Keyes. *B*, apical disk showing genital plates each with three pores (*G*), and ocular pieces (*O*). About nat. size. After Jackson.

occurred the forerunners of the regular echinids in the ancient cidarids (*Archeocidaris*) which had, however, more than twenty columns of plates.

Sedentary Echinodermata or Pelmatozoa

Crinids or Crinoidea (means *lily form*). — The crinids are popularly known as sea-lilies or stone-lilies, names that give very erroneous suggestions as to their nature, since they are animals and not plants. A better name is *feather-stars*. They are Echinodermata which are usually gregarious in habit and fixed to the sea bottom by a more or less long stalk; there are, however, also many free forms that crawl or swim around. They consist of three main

parts: (1) the *calyx* or body proper, (2) the *arms*, and (3) the *stalk*. The calyx and arms together are referred to as the *crown* (see Fig. 395, also Pl. 9, Fig. 4, and Pl. 6, Fig. 5). The calyx may be large or small and is made up of a variable number of closely adjoining plates, which are arranged in a very definite manner in the different forms, and the crinids are classified according to their arrangement — a scheme too complicated to describe here. From the upper part of the calyx arise the arms or radii, hardly ever less than five in number, and these may fork once or many times according to a regular or irregular plan, but most often in multiples of five. The arms are made up of single or double columns of plates and may have a regular series of small armlets arising from their inner edges and known as *pinnulæ*, suggesting the barbs on a feather (hence the name *feather-stars*). The ambulacra are situated along the inner sides of the arms and pinnulæ where the microscopic food is captured and conveyed to the mouth at the top of or within the calyx. The *anal aperture* is also on the upper or ventral surface of the calyx but is always more or less eccentrically situated and often drawn out into a long anal tube (Fig. 395 *A*). The stalk consists of many superimposed, disc-like, perforated pieces called columnals. It is usually short, from 6 to 18 inches in length, but in one Jurassic form attains 50 feet.

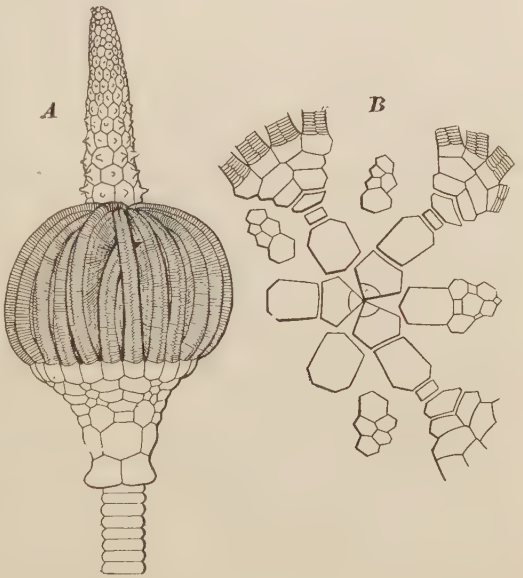


Fig. 395. — A box crinid (*Batocrinus pyriformis*) from the Mississippian of Iowa. *A*, stalk, calyx, arms, and anal tube, from the side. *B*, plates of calyx spread out to show shape and arrangement. After Keyes, Geol. Surv., Missouri.

Ancient Crinids. — In the Paleozoic, crinids at times were very common, especially the forms known as the box crinids (Camerata). In these, the calyx was large and box-like, with thick plates that usually held together tightly (see Pl. 19, Figs. 10, 11). Their

remains are sometimes so common as to make thick crinid limestones, this being especially true in the Mississippian formations.

Crinids appeared early in the Ordovician but are not common fossils until the Silurian, when they are plentiful, and remain so until near the close of the Paleozoic era. However, good crowns are rarities, although the fact that the crinids swarmed in the Paleozoic seas is attested by the many beds of crinid limestones. The cause of this lack of good preservation is that the loose skeletal pieces lay embedded in the skin, which readily decomposed on the death of the animals, and, as their habitat was in shallow seas, the moving waters washed the plates apart.

The crinids of the Mesozoic are less abundant and in American deposits are indeed very rare. They are very different from those of earlier times and more like those inhabiting deep water to-day. In Europe, crinids are common in the Triassic and Jurassic.

Blastids or Blastoidea (means *germ* or *bud*) are small, stalked, extinct Echinodermata that arose in early Ordovician time. In a broad way, these fossils resemble nuts and because of this the people in the southern states, where they are common, often call them "fossil hickory nuts" (*Pentremites*). We may say they are like crinids in their general construction, but they differ at once in that blastids have no arms, only delicate armlets called brachioles. These are situated at the sides of the five large and conspicuous ambulacral areas seen on the sides of the calyxes, areas which are practically never seen in crinids. In blastids the calyx is usually made up of thirteen plates (see Pl. 16, Figs. 1–3, Pl. 20, Figs. 6, 7).

Blastids appeared in the Ordovician, and, while often seen in Devonian strata, were not common in America until Mississippian time, when the seas abounded in them. They are guide fossils of this time, but died out early in the Pennsylvanian.

CHAPTER XXXVI

SILURIAN TIME AND THE FIRST AIR-BREATHING ANIMALS

Origin of the Term Silurian. — The term Silurian was proposed by the great English geologist, Murchison, in 1835, for a series of sedimentary and interbedded volcanic rocks which the older geologists called "Transition Rocks" or "Graywacke." These rocks occur in western England and eastern and southeastern Wales, the country of the ancient Britons known as Silures.

Fig. 396. — Roderick Impey Murchison (1792–1871). Author of Silurian, Devonian and Permian systems.

The original Silurian is now known to be overlain unconformably by fresh-water deposits called the Old Red sandstone, and referred to the Devonian; below, Murchison left his system undelimited and finally claimed all of Sedgwick's Cambrian strata that yielded trilobites and brachiopods. Because of this inclusion there arose between them a long controversy which, so far as terminology is concerned, seems not yet to be settled.

The upper boundary of the original Silurian long remained undefinable because of the absence of marine fossils and the erroneous conclusion that the beds passed gradually into the fresh-water Old Red sandstone. The adjustment was finally made in Germany (Harz region) and Bohemia, and, on the basis of this determination, the upper boundary of the Silurian in America is now placed at the top of a series of beds called the Manlius.

Murchison divided his system into a Lower and an Upper division. The boundary between them was finally established where an angular unconformity separates the Caradoc from the Llandovery groups, as first pointed out by Sedgwick. The controversy for the present is adjusted by calling all of Sedgwick's

Lower Cambrian that is almost unfossiliferous, Cambrian; his Upper Cambrian, to which he really wished to have the term restricted, and which Murchison called Lower Silurian, is now named Ordovician; while to the latter's Upper Silurian is now applied the period name Silurian.

American Silurian

Almost everywhere in North America the strata of the Silurian system are easily separated from the Ordovician below by a more or less long "break" or interval. Throughout the New England States and the Maritime Provinces of eastern Canada the two systems are separated by an unconformity marking the movement

Fig. 397. — Ordovician-Silurian unconformity at Otisville, N. Y. Above are conglomeritic sandstones (Shawangunk), resting on the peneplained surface of Ordovician shales (Martinsburg). Unconformity due to the Taconic Disturbance.

of the Taconic Disturbance (see Fig. 397), but in the great interior region of the continent the separation, as a rule, can only be made on the basis of the entombed fossils (see Fig. 398). On Anticosti Island in the Gulf of St. Lawrence may be studied the most complete American section. Even here, however, the two periods are seemingly separated by a break or interval.

The American Silurian is divided as follows:

Upper Silurian or Cayugan	Monroe group. Salina group	Manlius the youngest formation
Middle Silurian or Niagaran	Guelph dolomite Lockport dolomite Rochester shale Clinton formation	Louisville limestone
Lower Silurian or Oswegan	Medina, Cataract, and Brassfield formations Becsie limestone	

Advance and Retreat of the Seas in America. — Unlike those of the Ordovician, the Silurian deposits of America record but a single oceanic spreading and a single continental emergence. During Lower Silurian time, the small seas were at first situated on the

Fig. 398. — Ordovician-Silurian disconformable contact, Niagara River gorge, N. Y. Note even contact of white Silurian sandstone (Whirlpool-Cataract) on brick-red, sandy, Ordovician shales (Queenston).

northeastern part of the continent and later in the Appalachian trough, as shown on the paleogeographic maps. In Middle Silurian time, the marine waters flooded the continent widely, especially in the northern half, and attained the maximum of their spread toward the close of this time (Louisville), when it is thought that from 35 to 40 per cent of North America was under water. The submergence retreated shortly afterward, the Central Interior sea withdrawing first, and later the Arctic waters. During the Upper

Silurian epoch a very shallow sea remained in the northern Appalachian and Central Interior areas, depositing along its northern shores considerable salt and gypsum. It is probable that toward the close of the Silurian the entire continent was emergent, except a small part of the Appalachian trough in Maryland and Pennsylvania and the outer St. Lawrence trough (Gaspé).

Cincinnati Uplift. — This low arch, described in Chapter XXXIV, was not a marked topographic feature in the seas of Ordovician time (see page 636), but throughout the Silurian distinct marine basins lay on either side of it. Floods from the Gulf of Mexico extended northward and covered the areas to the east and west of the arch, but along the western side the waters were most persistent during the Niagaran epoch. The Ozark uplift was also a striking feature of these seas, confining the southern floods to its eastern and southern sides in eastern Missouri, Arkansas, and central Oklahoma.

If the Middle Silurian flood at its height be compared with the greatest submergences of the Cincinnatian and Champlainian epochs of the Ordovician, it is seen that great changes had taken place, for there was much more emerged land in the western part of the United States during Silurian time than before. Great areas were upwarped and persisted there as lands even long after the Devonian.

Character and Thickness of Silurian Rocks. — *Eastern United States.* — In the Appalachian trough the sedimentaries are coarse-grained throughout until near the close of the Silurian, when much compact or dense cement rock or water limestone was deposited in very shallow seas, as is indicated by its very decidedly sun-cracked nature. These coarse-grained rocks are the results of rapid erosion from the high lands of Acadia following the Taconic Disturbance. In east-central Pennsylvania the thickest accumulations occur, with a maximum of 6490 feet. Of this mass the lower 4490 feet are almost devoid of limestones, the strata being cross-bedded sandstones, sandy shales, shales with a little sandy limestone, and, toward the top of the series, local beds of valuable fossil iron-ore. The upper 2000 feet of Upper Silurian age consist of shales gradually becoming more and more calcareous toward the top, which, in New York, Ohio, and western Ontario, bear valuable deposits of rock salt and gypsum. This great mass of Silurian material thins rapidly to the south and north and probably also to the west under the coal fields of the Allegheny region. In the Niagara Falls area of New York there are about 180 feet of shale, sand-

stone, and dolomite that thicken rapidly to the south under the cover of the younger strata. At the Virginia-Tennessee line there are not more than 400 feet of basal sandstone (Clinch) followed by 325 feet of shales and sandstones (Dyestone) of Middle Silurian time. South of Tennessee these beds again thicken, there being in the Appalachian trough of northwestern Georgia 1600 feet of Middle Silurian strata which thin rapidly to the west end of the state, where 180 feet are present (see Pl. 10).

Acadia. — In eastern Acadia the Silurian is widely spread and often rich in fossils. The thickest section is at Arisaig, Nova Scotia, where there are nearly 4000 feet of shales and sandy limestones. Another fine exposure is that of Anticosti Island in the Gulf of St. Lawrence, with more than 1200 feet of limestones and some shales representing the earliest portion of the American Silurian; the higher beds continuing the section are present farther south along the north shore of the Bay of Chaleur, Quebec. In southern Maine the Silurian is locally very thick, there being in the Penobscot Bay region about 10,000 feet of volcanic tuffs and detrital land sediments. This thickness, however, does not include the volcanics and lava flows, which also have considerable depths.

Silurian Sequence at Niagara Falls. — Between Buffalo, New York, and the region about Niagara Falls may be studied a typical Silurian section and one of the finest exposures in America for fossils of this time. The gorge between the Falls and Lewiston has the lowest strata reposing on the Ordovician, while the younger deposits appear in sequence toward Buffalo, where some of the Middle Devonian is also to be seen in the Bennett quarries. The diagram, Fig. 399, shows the sequence of the beds and Fig. 400 pictures them as they appear in the walls of the gorge of Niagara River. All of the strata have a gentle dip southward.

Interior of North America. — Here the Silurian seas had clear waters, and their deposits were almost entirely calcareous. Almost all of them were of Middle Silurian time. The strata were widely distributed in two epeiric seas, one being the smaller southern Central Interior sea and the other the far larger sea of the Arctic region. Nowhere are these deposits thick when compared with those of the Appalachian trough, and, unlike the latter, they are largely limestones, dolomites, and calcareous shales, with almost no sands. In no place does the thickness exceed 1000 feet and in general it is usually considerably under 500 feet.

Rocky Mountains. — The Silurian of western North America is not yet well known and appears to be poorly developed through-

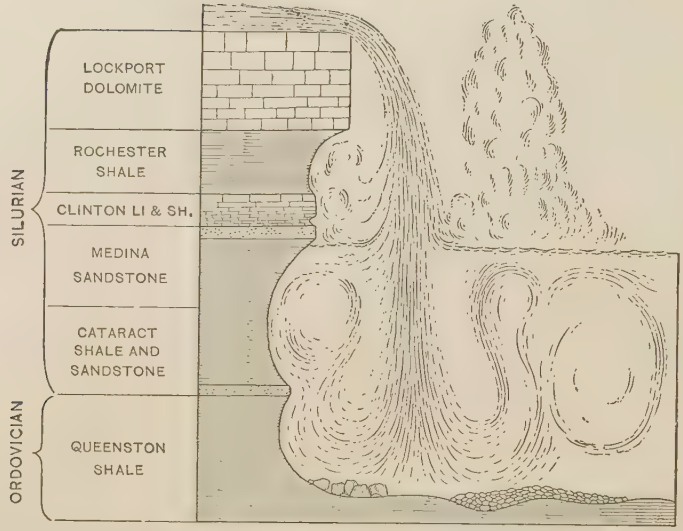


Fig. 399. — Sectional diagram through Horseshoe Falls, Niagara River, showing sequence of formations and depth of water below falls. Height of falls, 158 feet; depth of water, 150–200 feet. Modified from G. K. Gilbert.

Fig. 400. — General view of New York side of Niagara River gorge. Clinton limestone at track level, the long slope is Rochester shale, and the vertical upper walls are Lockport dolomite.

out the United States. In the Cordilleran sea of Canada, however, there was another deep trough, for near the International Boundary (Bow Pass) there are 1300 feet of dolomites and quartzites. This trough deepened northward, since in the western Mackenzie valley (Gravel River) there are 2000 feet of dolomites, and in Alaska at the Lower Ramparts of the Porcupine River there are 2500 feet of dolomites with some black shale. In southern Alaska in the region of Kuiu Island there are 2000 feet of limestone (see Pl. 10).

In the southern portion of the Cordilleran sea little is known of the Silurian deposits, but such are seen to occur in Nevada and in the Utah area of the Great Basin, where 200 to 300 feet of magnesian limestones have unmistakable Silurian fossils. In the Franklin Range of western Texas there is another Silurian area of a distinct sea, also apparently of Pacific origin; here there are 1000 feet of Middle Silurian limestones.

Life of the Silurian

Marine Provinces. — On the basis of their entombed faunas the American Silurian deposits are geographically divisible into three provinces. These are (1) Atlantic, (2) Arctic, and (3) Cordilleran (see Pl. 10). The best known of these, with the longest and least broken record, is the Atlantic province, embracing the Silurian deposits of the Acadian area and the Appalachian trough. The Arctic province is only of Middle Silurian time, includes much of the northern interior parts of the continent south almost to the Ohio River, and has decided faunal connections with the Baltic area of northern Europe, the intercommunication being by way of northern Greenland. In the Cordilleran sea the Silurian faunas are not well known, but appear to be of Pacific origin.

Marine Invertebrates. — As is usual in marine sediments, practically nothing of the soft sea plants is preserved, although the Silurian life record is almost entirely that of the shallow seas wherein algæ abound. The invertebrates still dominated the seas because the fishes were as yet not at all prominent, though appearing more abundantly in the late Silurian seas of Europe. The common Silurian fossils are mainly corals, crinids, bryozoans, brachiopods, and trilobites (see Pl. 9). Of nautilids there are less than a hundred kinds known in America, but in Bohemia, where the sea had Mediterranean connections, the warmer waters swarmed with them, Barrande having described from this small area 1150 species. The Silurian was, however, the time of greatest nautilid development

and since then there has been a steady decrease in number of species. True graptolites were still common in the European seas, but in America they are not often found as fossils, although the dendroid forms are, in places, common, as at Hamilton, Ontario, where 52 species occur.

Of crinids there are nearly 400 kinds known in the American Silurian, a far better development than in the Ordovician; many of these beautiful fossils have thick calcareous skeletons and are therefore spoken of as box crinids (Camerata, described on page 657). These crinids must have existed in great numbers, for their skeletons often make up thick limestones. The bryozoans were

Fig. 401. — Small reef made by bryozoans, Niagara River gorge, N. Y. The reef (15 feet long) rests on Clinton limestone and projects into Rochester shale.

also common, about 200 forms being known, but while they made small reefs in the Clinton, they were not so prolific as in the Ordovician (see Fig. 401).

Of brachiopods there are about 350 kinds described from the Silurian of America (see Pl. 9). Although their general development was still much like those of the Ordovician, they were, on the average, larger and more robust. There was also at this time a distinct change in the introduction of many forms that have internal spiralia or calcareous supports for the arms (page 611), and in the abundance of rhynchonellids and pentamerids.

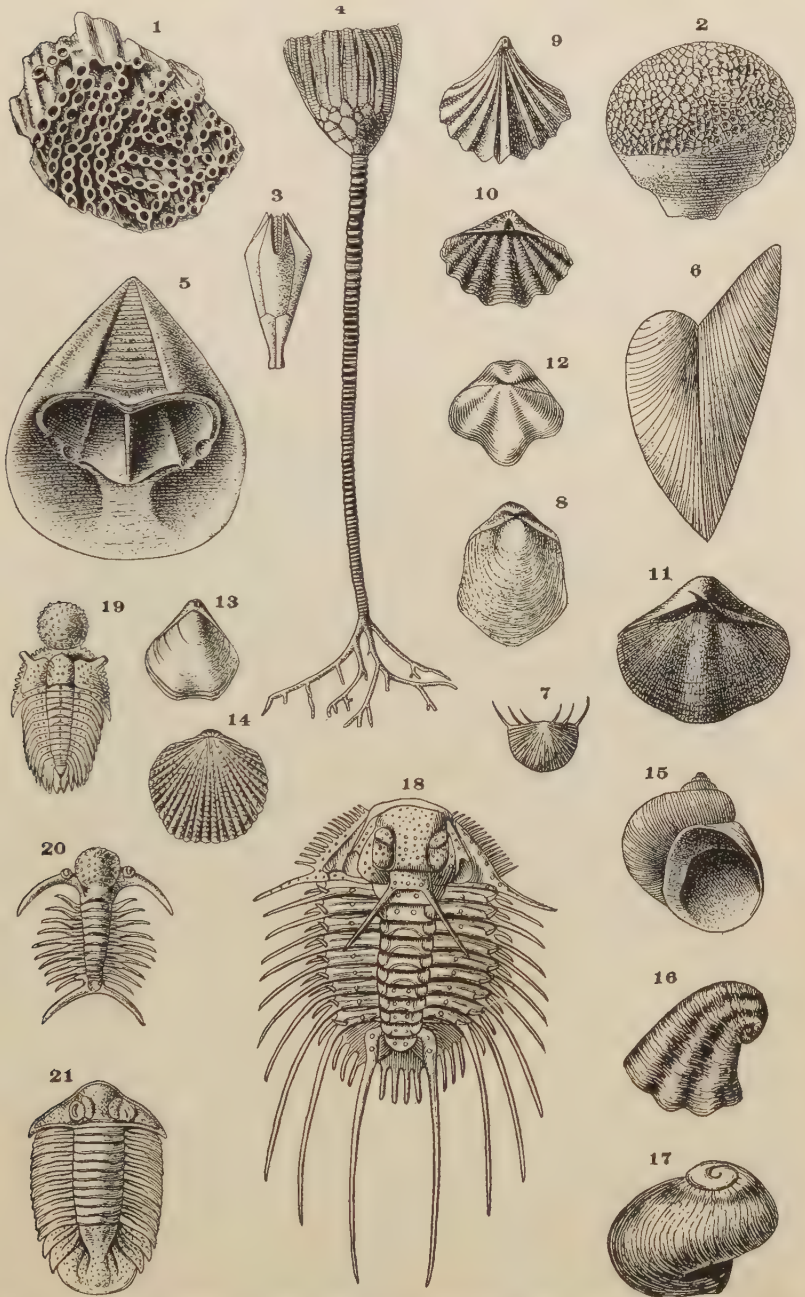


Plate 9. — Silurian corals (1, chain coral; 2, honeycomb coral), blastid (3), crinid (4), brachiopods (5–14), gastropods (15–17), and trilobites (18–21).
See Appendix B.

Of trilobites there were still at least 105 American species, many of which were bizarre looking animals with many spines on the head and tail (see Pl. 9). Spinosity is often interpreted as indicating an ebbing of the vital force among the trilobites, but in some forms it may have been a protective device against the carnivorous fishes then coming into being.

Throughout the Silurian, but more particularly in the Upper Silurian, the "sea scorpions" or eurypterids were common (see Pl. 12). They usually occur in brackish-water deposits that otherwise are devoid of fossils, and very similar kinds are found in

Fig. 402. — Silurian coral reef limestone, near Wisby, Gotland, Sweden. The coral reef lies above the regularly bedded limestone.

both eastern America and western Europe. The largest American species is found in New York (*Pterygotus buffaloensis*), where Clarke and Ruedemann have determined for it a length of nearly 9 feet. The eurypterids are particularly interesting in this connection, not only because they are so characteristic of late Silurian time, but also because out of them arose the air-breathing scorpions.

Coral Reefs. — Corals were not common until the Middle Silurian, and then at many places in America they made reef limestones (see Figs. 402 and 145). The best examples of these are seen in Wisconsin, Iowa, and the Manitoulin Islands, and to a more limited extent

at Louisville, Kentucky. All of these corals are of the kinds known as Tabulata and Tetracoralla, described in the previous chapter.

Associated with the coral reefs, more especially toward the close of the Middle Silurian (Guelph), are seen many thick-shelled animals, most of which are gastropods. Fifty species of these have been described from a limited area (Ontario). Similar associations are seen on the present living reefs, where the molluscs form thick shells, not only because they are necessary against the crushing power of the active waves, but also because there is much lime in the warm sea-water which can be easily extracted.

Cosmopolitan Character of Middle Silurian Life. — The known marine life of Lower Silurian time is scanty, but that which can be found indicates that each area had its own peculiar assemblage. The same is also true of the earliest Middle Silurian faunas, but it is not so marked as in the earlier time. Finally, when the inundation of the continent was greatest, in Middle Silurian (Louisville) time (Pl. 10), the faunas of all the provinces took on a more cosmopolitan appearance and had the greatest number of species in common. At this time there were at least thirty forms in common between northern Europe and America, this similarity being greatest in the Arctic province, a sea in open connection with Europe by way of northern Greenland.

First Land Plants. — The known land plants of Silurian time are as yet exceedingly few, and the specimens are rather indistinct. For these reasons the discussion of the nature of the first land flora is deferred to a later chapter.

First Land Animals. — *Fishes* undoubtedly lived in the fresh waters throughout this period, but almost nothing is known of them until late in Silurian time, when their skeletons are met with in Europe. As they are so much like those of the Devonian, a description of them is postponed until a later chapter.

The *scorpions* of the Silurian are the oldest known air-breathing animals (Fig. 403). They probably had their origin in the eurypterids of the sea, seemingly as early as the Ordovician. The largest one known was 2.5 inches long, and in general structure they were very much like the living scorpions, which live entirely on land. The question therefore arises: Were the adult Silurian scorpions wholly adapted to the dry land, or did they live along the seashore between the tides? Their remains are rarely found in marine deposits, but usually in those of brackish water, and associated with the eurypterids, which would seem to indicate a littoral habitat. Scorpions are carnivorous animals, and the living forms feed on

insects, spiders, and other small forms, killing the prey with their poisonous tail sting. We may assume that the Silurian species lived as do those of the present, and, as the latter are wholly terrestrial, the further question suggests itself: On what could the Silurian forms have fed, since no insects, spiders, or even land snails

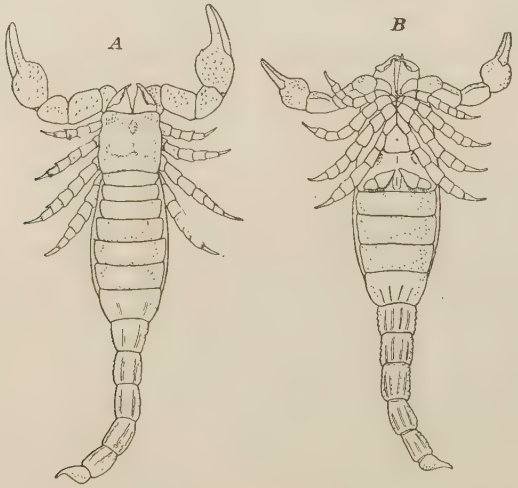


Fig. 403. — Two species of Silurian scorpions, restored. *A*, dorsal side of a Swedish form (*Palæophonus nuncius*). *B*, an English species (*P. hunteri*) from the ventral side. After Pocock.

are known at this time, or for that matter previous to the Carboniferous? As spiders are closely related to scorpions, and as species of the former are known along most sea-coasts, inhabiting the beach between high and low tide, it seems, therefore, a safe inference that the Silurian scorpions also fed and lived, when adult, above the strand-line, though, like frogs, they may have lived in the water during their period of infancy, and that they ate small invertebrates, among them trilobites and small crustaceans. Their wanderings over the land began later with gradual adaptations away from the life of the shores, but this migration could have taken place only when the land had other animals for them to feed upon.

Silurian Climate

As the Silurian seas abounded in varied life and as the deposits in the main were limestones and dolomites even as far north as the Arctic regions, it is safe to infer that these waters were warm. Additional confirmation is had in the fact that the life of the

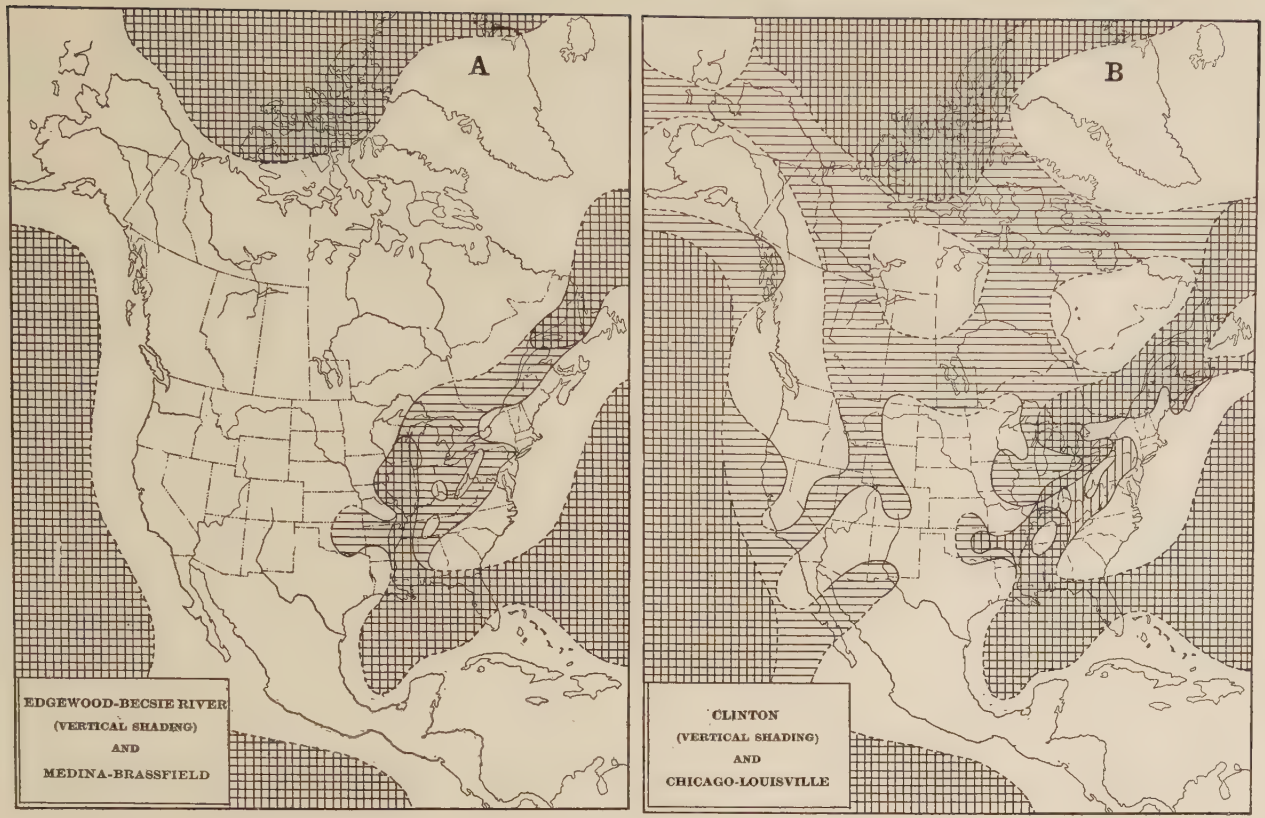


Plate 10. — Lower and Middle Silurian paleogeography.

American Arctic deposits is very much like that of northern Europe and of the United States, while the reef-building corals are practically everywhere the same. The chain coral (*Halysites*, Pl. 9, Fig. 1) and the honeycomb coral (*Favosites*, Fig. 2) are very similar in all the areas, and are found even above 81° north latitude at Polaris Bay. Further, extensive salt-depositing seas existed in eastern North America between 40° and 45° north latitude, indicating an arid or dry climate on the land, though it is not necessary, because of this evidence, to assume that the temperature was hot. We may therefore conclude, on the basis of the character of the deposits and of the life, that the climate of Silurian time, in the northern hemisphere at least, was temperate to warm.

Caledonian Disturbance of Western Europe

An extensive ancient land had long existed immediately to the northwest of Ireland and Scotland, and its rivers brought down into the sea area, now Wales and southern Scotland, 12,000 feet of Cambrian and at least 10,000 feet of coarse Ordovician deposits. During the earlier half of Ordovician time a line of volcanic islands stretched across Ireland and the north of England in a southwest and northeast direction, and there is in the Cambrian area at Keswick at least one pile of volcanic ejected materials fully 12,000 feet thick. The deformation toward the close of the Ordovician, as the result of this loading, was, however, not wide-spread, for Geikie states that in Wales these strata were ridged up into a series of islands, around the margin of which the conglomerates at the base of the Upper Silurian series began to be laid down. Of Silurian deposits there follow 6000 and in places even 15,000 feet, which locally lie discordantly upon the Ordovician, the deposition going on until well toward the end of the former period, when there occurred the culmination in the making of the Caledonian mountains, ranges that extended from Ireland and Scotland as far as Spitzbergen. Other ranges also came into being in France and Belgium. That these movements took place late in the Silurian is shown by the fact that the Devonian Old Red sandstones were not involved in the foldings and thrustings, while the youngest strata in the folds are of late Silurian time.

With the Caledonian Disturbance is probably to be connected the withdrawal of the seas in North America and in northern Europe, the emergent period lasting through all of late Silurian and early Devonian time.

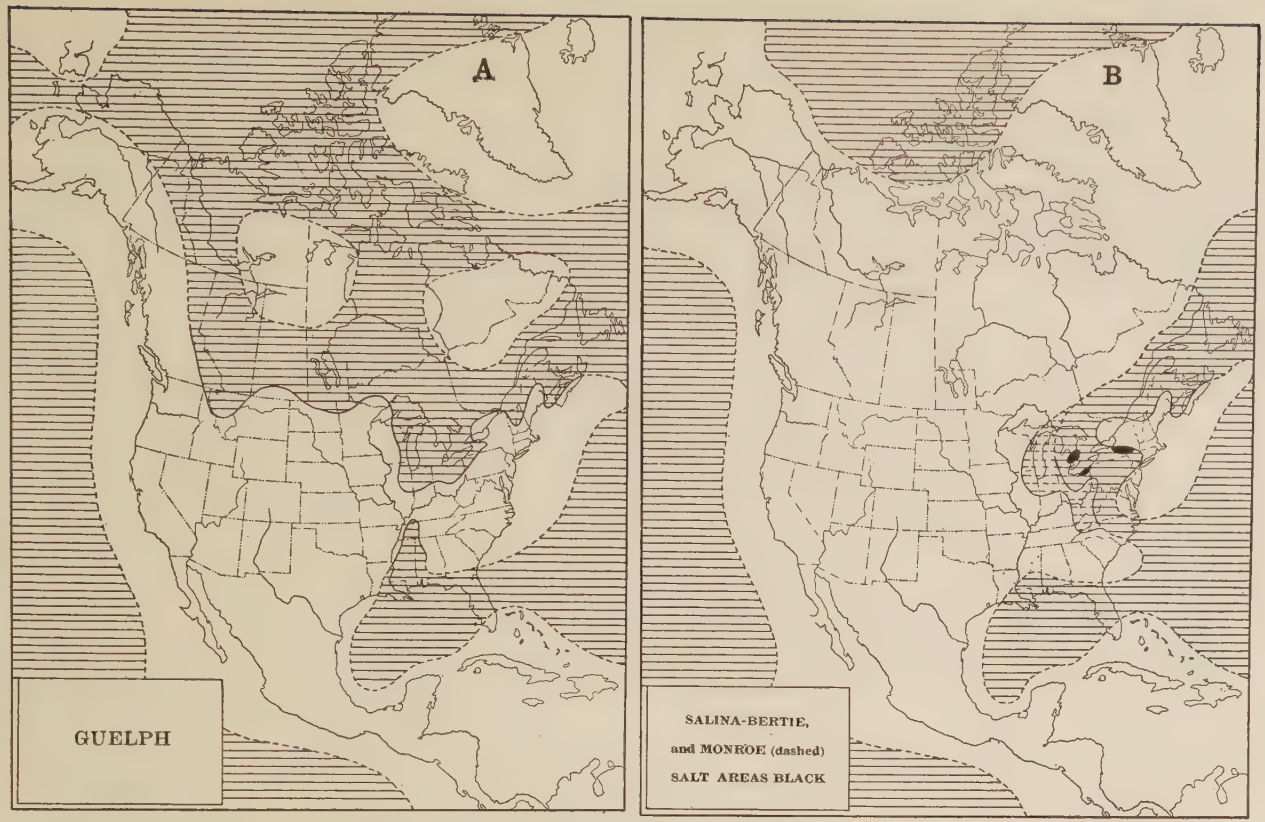


Plate 11. — Middle and Upper Silurian paleogeography.

This crustal movement, resulting in the Caledonides, as Suess terms these mountains, may be regarded as the first important stage in the building of the British Isles, and the Caledonian range must have been much grander and loftier than the Alps (Jukes-Brown). The significance of the movement is best seen, however, in Norway and Sweden, where the pre-Devonian strata have been overturned and pushed horizontally eastward at least 86 miles. The thickness of the moved mass is usually less than a mile, but originally it must have been much greater. On the other hand, it appears almost certain that the Scandinavian countries have for a long time lain at a low level in respect to that of the sea, for great parts of Norway and Sweden were again invaded by it in late Cretaceous time. The present mountainous character of Norway is undoubtedly due to deformation in late Tertiary time, an elevation that must have been a few thousand feet higher then than now, as proved by the deeply submerged marginal valleys, the beautiful fiords of Norway.

Rock Salt

Occurrence. — Rock salt and gypsum may have accumulated in the sedimentary strata at any time and place when the necessary physical conditions, discussed on pages 76 to 79, were present. In America extensive salt-depositing basins came into existence toward the close of the Silurian (Salina formation) in New York, Ohio, and Ontario (Pl. 11, Fig. B). The salt brines of western West Virginia, on the other hand, rise from rocks of Upper Devonian age and those of southeastern West Virginia are of early Mississippian time, while in southern Louisiana occurs rock salt of Tertiary age. The most interesting and by far the thickest beds, however, occur in Germany near Berlin (Sperenberg, 3250 feet of marine salt), and at Stassfurt in southern Saxony, where there is an average thickness of 3400 feet of salts. These deposits are of Middle and Upper Permian time. At Stassfurt occur more than thirty saline minerals, and it is estimated that the salts here were accumulated in less than 10,000 years, a calculation based on the many so-called annual layers which are clearly demarcated.

Silurian Salt in New York. — The Salina formation of New York consists mainly of reddish shales with some thin bands of dolomite. Its outcrops extend as a narrow belt across New York State from the Helderberg Mountains westward to Niagara Falls, where the thickness is 380 feet in well borings. From this belt the strata dip southward beneath the younger formations, and 25 miles nearly south of the Batavia outcrops they are 1000 feet beneath the surface, and 1500 feet at a distance of 33 miles. At Syracuse the thickness of the formation is about 600 feet, at Ithaca 1230 feet. Salt springs occur in many parts of New York west of Syracuse and Tully. Rock salt occurs in New York at depths of 800 to 3000 feet or more, over an area measuring 150 miles from east to west, and 60 to 65 miles in width if regarded as extending only to the Pennsylvania boundary. The northern limit of the area is near Morrisville, where 12 feet of salt were found, and near Leroy, 100 miles west of Syracuse,

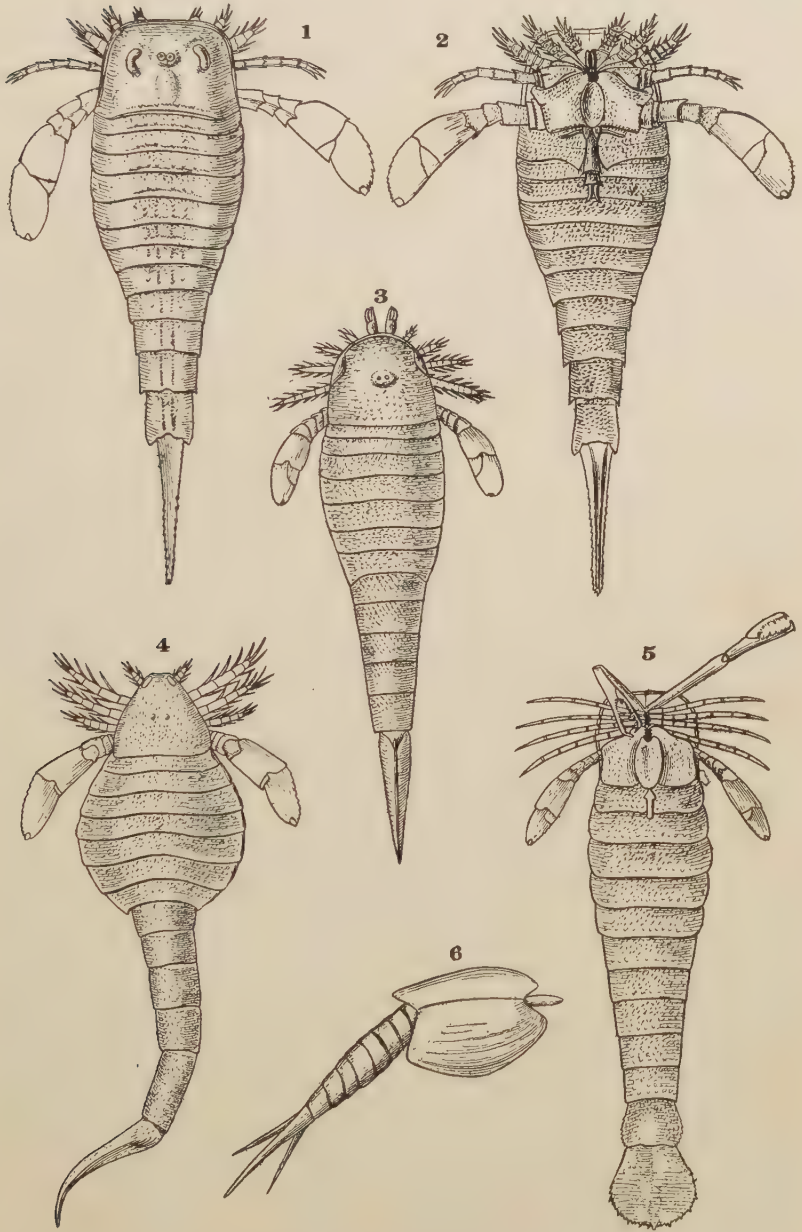


Plate 12. — Silurian eurypterids (1–5) and a phyllopod crustacean (6).
See Appendix B.

where a bed 40 feet thick exists. In Livingston and Wyoming counties the salt beds have an aggregate thickness of 50 to 100 feet, some beds of pure salt being 40 to 80 feet thick. At Ithaca the seven beds of salt have together a thickness of 250 feet and they alternate with shale between depths of 1900 and 3130 feet. (Dana.) For distribution see map, Pl. 11, Fig. B.

Theory of Salt Formation. — Beds of rock salt, in a section, may be separated from one another by clay, limestone, or dolomite, or there may be a single bed of very variable thickness and made up of many kinds of salts.

Ocean water contains, on the average, about 3.5 per cent of solid matter in solution, most of which is sodium chloride or rock salt (78 per cent of the sea salts), and it contains also calcium sulphate or gypsum (about 3.5 per cent) (see page 83). The two compounds are commonly associated with each other, but not invariably, for gypsum is sometimes derived from other sources, and rock salt may be dissolved and washed away from a given locality, leaving the gypsum. Still, concentration of the oceanic salt water is the principal source of these deposits. In general, the following is the order of deposition: (1) precipitates of lime carbonate and some hydrous iron oxide; (2) most of the gypsum, which precipitates when 37 per cent of the sea water is evaporated; (3) mixtures of gypsum and common salt; (4) pure sodium chloride, when 93 per cent of the original water is gone; (5) in exceptional conditions, mixtures of sodium chloride with salts containing magnesium, potash, bromine, and iodine. This order, however, is subject to seasonal alterations, variations in temperature, and other conditions, so that alternations of gypsum, salt, and clay are exceedingly common in saline deposits.

It is probable that all of the more extensive accumulations of sodium chloride and calcium sulphate are connected with marine sedimentation, under dry, warm, or cool to even cold climates, in very shallow seas or bays more or less shut off from the oceans by land bars or barriers and previously described as detached salt lakes (page 79). The essential conditions are (1) a dry climate constantly taking away by evaporation some of the water in (2) nearly land-locked seas, and (3) the supplying of the loss at frequent intervals (high tides) from the oceans. These waters must, therefore, be practically free of circulation, at least with no greater flow than that produced by the tides at the heads of bays. The Salina sea must have been an extensive shallow basin with openings out into the Atlantic Ocean.

Absence of Fossils in Salt Beds. — In basins supersaturated with salts one naturally would not expect much life, and when the

saturation is marked (15 to 22 per cent) they are dead seas. Even where the saturation is but a little above that of the ocean, animal life becomes scarcer and the molluscs make thicker and rougher shells. The Salina and Permian seas in the places of salt accumulation were lifeless.

Other Economic Products

Clinton Fossiliferous Iron-ore. — In the Clinton formation of the Appalachian trough from New York to Alabama, there occur in many regions one or more beds, varying from a few inches to 10 and even 20 feet in thickness, of regularly stratified, argillaceous, red iron-ore or hematite (Fe_2O_3). They were formerly mined throughout the Appalachian Mountains, but now are worked extensively only in the Birmingham region (Red Mountain) of Alabama. The ore is usually more or less cross-bedded, fossiliferous, and made up of clay, oolites, and the fragments of invertebrate animals, the calcium carbonate of which is now more or less replaced by ferric oxide; the deposits are, therefore, often called "red fossil ore." The beds were evidently made in storm-beaten shallow seas where trituration or breakage of the shells was marked, with a loss of the carbonic acid. Frequently, the grain of the ore is similar to that of oolitic limestone or the particles are flattened like flaxseed, and accordingly the ores are also spoken of as oolitic and flaxseed iron ores. In Tennessee, they are known as the Dyestone ores.

Clinton Oil and Gas. — In recent years, the Clinton sandstones of central Ohio and eastern Kentucky have yielded locally considerable oil and some gas.

Geological Map. — The surface exposures of Silurian strata are shown on the Geological Map of North America at the end of this book.

CHAPTER XXXVII

FISHES AND THE ANCESTORS OF VERTEBRATES

The word fish, from the Latin *piscis*, is a very old one and popularly has reference to any animal that spends its entire life in the water. Therefore, the word, as commonly used, covers a variety of unrelated animals, some of which are distinguished by a prefix, as jellyfish, starfish, shellfish. None of these are fishes in the sense in which the term is used by naturalists, whose class name *Pisces* includes only the true fishes, animals with backbones but of great structural diversity and also of great antiquity, whose history may be traced to at least the middle of the Ordovician. The fishes in the strict sense form a class of the subkingdom Vertebrata, with the same rank as the Amphibia (frogs and salamanders), Reptilia (turtles, crocodiles, lizards, snakes), Aves (birds), and Mammalia (dogs, horses, man).

Fishes were the first markedly successful class of vertebrates. With the possession of a vertebral column and a central nervous system, and with their greater alertness, mobility, and fecundity, they have an easy preëminence over their invertebrate inferiors. They are as markedly adapted to the water as the birds are to the air.

Definition of Fishes. — Fishes are vertebrates without a movable neck and with a distinct and hinged *lower jaw*. With few exceptions, they pass their whole life in water. Their body temperature is about that of the medium in which they live, wherefore they are said to be cold-blooded. Because of their water habitat, all fishes have *gills* and *fins* (see Fig. 404). The gills are on each side of the head and consist of delicate, hollow filaments in which the blood circulates, and which are supported by internal gill arches of either cartilage or bone. Water is taken in through the mouth and passed out over these breathing organs, where the blood in the tubes extracts the free oxygen dissolved in it. The external gill openings may remain open and unprotected or may be covered over by a hinged bony cover, the *operculum*. The *mouth* may be on the under side of the head or at its forward end, and is usually provided

with teeth. An *air bladder* is generally present and serves as a hydrostatic organ or float, though in certain forms it acts as a lung and assists the gills in respiration.

The heart, which is two-chambered, contains only venous blood, that is, blood which it is pumping through the veins to the gills to be purified; in the Dipnoi, or lung-fishes, however, it shows signs of becoming three-chambered, and receives pure blood from the lungs as well as impure blood from the body. In all the fishes except the Dipnoi, one chamber of the heart, called the auricle, receives the impure blood from the body, and the other cavity, the ventricle, drives this through a ventral aorta to the gills, whence the purified blood flows to the head, and then, by a dorsal aorta, or artery along the back, is carried to the body.

The skin is either soft and naked, or, more commonly, protected by the development of spines, overlapping scales, or bony plates known as scutes. The principal organ of locomotion is the power-

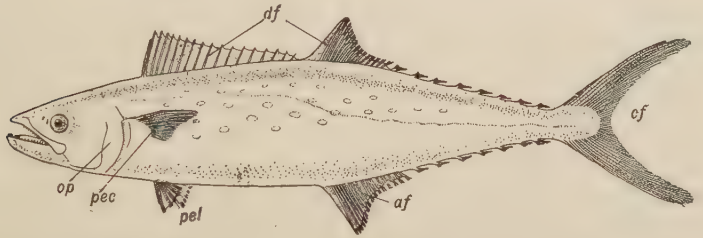


Fig. 404. — Spanish mackerel, a swift-swimming fish, to show external parts. After Goode. *af*, median anal fin; *cf*, caudal or tail fin; *df*, dorsal median fins; *op*, left operculum or movable covering over gills; *pec*, one of the front paired or pectoral fins; *pel*, paired pelvic fins, which may in different fishes be situated anywhere from this position back to a place in front of the anal fin.

ful and very flexible muscular tail. This is assisted by the *paired fins*, of which the forward set, known as the *pectoral limbs*, lie just behind the gills, and the rear pair, or *pelvic limbs*, are placed farther back (see Fig. 404). The paired fins of fishes correspond to the fore and hind limbs of the higher vertebrates. Their skeleton, however, cannot be readily compared with the limb-skeleton of other vertebrates, because it has not the same bones nor the five toes which are, with few exceptions, so regularly present in all higher vertebrates. Fishes also usually possess a variable number of *unpaired median fins* that are used mainly as balancing organs; those on the back are called *dorsal fins*, those on the under side between the anus and tail are known as *anal fins*, and the tail represents a *caudal fin* (see Fig. 404). All the fins are supported by skeletal bars or rays, called fin rays, and are covered by muscles

and skin. The skeleton throughout may be of cartilage, though usually it is more or less bony. The main skeleton consists of the *vertebral column*, made up of joints known as vertebræ, and the complex bones of the head, which serve also as a protective covering for the brain. The bones of the head are of two kinds, dermal or skin bones like the scales, and the actual bones of the brain case. Fishes do not have ears, and therefore there is no ear drum or tympanum (ear cavity) and no tympanic membrane. The *main nerve trunk* lies on the upper or dorsal side of the vertebræ, which extend from the brain case to the tail, and it is more or less protected by a bony arch known as the neural arch. Beneath the vertebral column are situated the digestive and reproductive organs.

Types of Fish Tails. — The tail presents three general types. (1) The vertebral column may be straight at its posterior end, continue in constantly diminishing joints nearly to the end of the animal, and be there surrounded by a symmetrical vertical tail fin. This is the most primitive type, very common among the Devonian fishes, and seen in the baby stages of most living fishes; it is known as the *diphycercal* or symmetrical tail (see Pl. 14, Fig. 4). (2) In others, the vertebral column bends upward toward the dorsal side and terminates with diminishing joints in the upper lobe of the dorsal fin. Hence, this type of tail is rarely symmetric but is commonly unevenly lobed as in the living sharks and in most Paleozoic fishes; it is called the *heterocercal* tail because of the inequality of the lobes (see Pl. 13, Figs. 2 and 4, Pl. 14, Figs. 1, 2). (3) The modern bony fishes also have, as a rule, a symmetric tail, but, while the vertebral column here again bends upward, it ends rather abruptly, and from the terminal joints the fin rays develop in such a way as to form a symmetric tail. This kind of caudal appendage is called *homocercal* (see Fig. 405); while the tail is symmetric it also has two lobes, whereas the diphycercal type has but a single lobe.

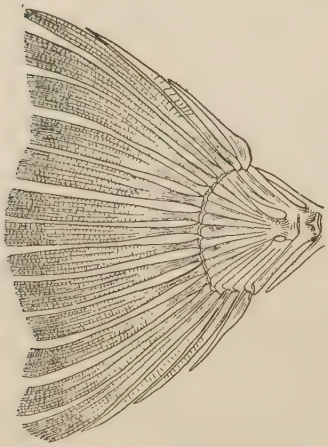


Fig. 405. — Skeleton of the homocercal tail of a flounder.

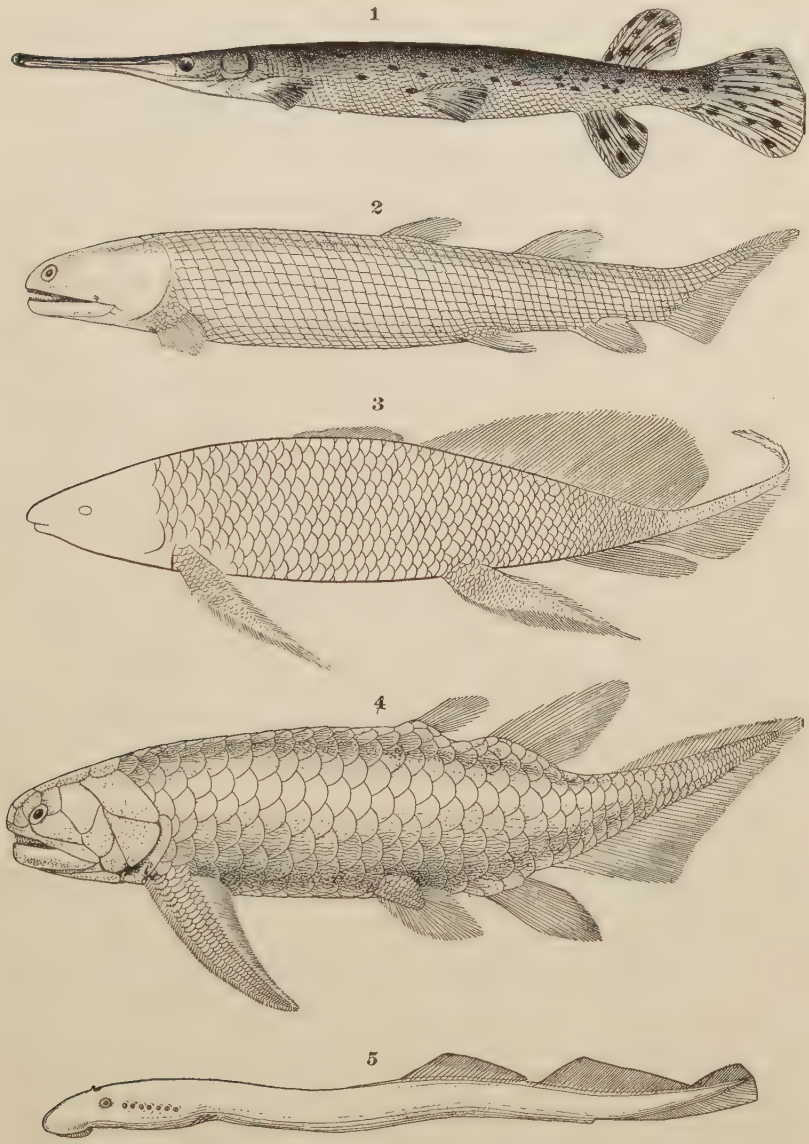


Plate 13. — Living ganoid (gar-pike) (1), fossil ganoids (2–4), and living marine lamprey (5). See Appendix B.

Classification of Fishes. — For present purposes, fishes may be divided as follows:

Class **Pisces** or true fishes.
- Subclass **Elasmobranchii** or cartilaginous fishes.
  - Order **Acanthodei** or spinous sharks.
  - Order **Selachii** or true sharks and rays.
- Subclass **Ostracodermi** or bony-skinned fishes.
- Subclass **Dipnoi** or true lung-fishes.
- Subclass **Arthrodira** or armored fishes.
- Subclass **Ganoidei** or enamel-scaled fishes.
- Subclass **Teleostei** or bony fishes.

Class Pisces or True Fishes

Subclass Elasmobranchii or Cartilaginous Fishes

The word Elasmobranchii means *having plate-like gills*, and the group includes the ancient and modern true sharks, sawfishes, sea-cats (*Chimæra*), skates, and rays. With few exceptions, the living forms are inhabitants of marine waters (see Pl. 14, Fig. 3).

In most elasmobranchs the mouth is on the under side of the head, but in some it is at the forward end. The internal skeleton is cartilaginous, with more or less calcification (not ossification, as that implies bony structure), but no members of the subclass have complete bony skeletons. The tail is usually heterocercal. The skin often appears to be naked, but there are always dermal denticles (small pieces) tipped with hard, shining enamel, cored with dentine (phosphate and carbonate of lime with fluoride), and with a bony (phosphate of lime) base sunk in the dermis or deeper part of the skin. This type of scale is called *placoid*, and has the same structure as teeth, which originally also developed out of the skin. When the denticles are small and closely set they constitute the so-called *shagreen* (meaning a rough mosaic).

The five gill slits on either side of the body back of the head are, in living cartilaginous fishes, either open or covered by a skin flap, never by a bony operculum as in most other kinds. The median fins are often provided with long, sharp, horny or bony spines, this being particularly true of the dorsal ones. It is these spines and the teeth of sharks that are usually preserved as fossils; unfortunately, however, they give little information as to the general characteristics of the animals.

The brain is enclosed in a solid cartilaginous box or skull without sutures or joints, and in this feature the elasmobranchs differ from nearly all other fishes (the exception being rarely among ganoids), in which the separate skull bones are easily distinguished. There

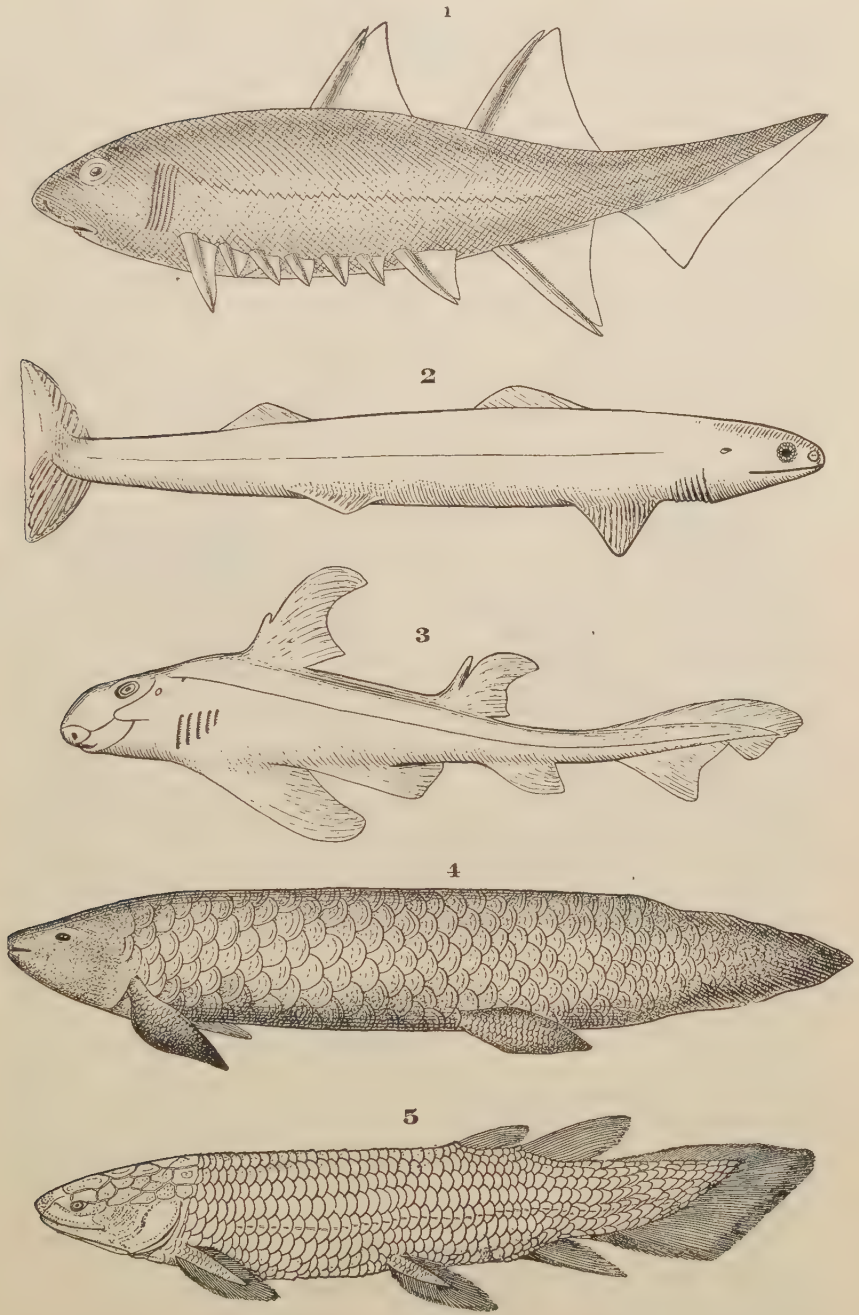


Plate 14. — Devonian sharks (1, 2), living Port Jackson shark (3), Australian lung-fish (4), and Devonian lung-fish (5). See Appendix B.

is no swimming bladder, and the large intestine or rectum is peculiar because it is always provided, on account of its short length, with an internal spiral membrane or fold, which serves to increase the absorbing surface. This is often seen in the fossil forms since Upper Devonian time and it is also present in the lung-fishes and ganoids.

Geologic Occurrence. — In America the oldest fossil evidence of elasmobranchs is that of small fin spines occurring in the early Silurian (Clinton) of Pennsylvania. Other spines occur near the top of the Silurian, and in Europe, where the specimens are more numerous, the oldest are from about the same horizon (Upper Ludlow bone bed). In the American Devonian there are 39 species, in the Mississippian 288, in the Pennsylvanian 55, and in the Permian 10. Therefore there was apparently a very rapid evolution

Fig. 406. — Cochliodont (*A*) and cestraciont (*B*) teeth of primitive sharks. *A*, jaw with two large tooth-plates (*Cochliodus contortus*). *B*, upper jaw, with many teeth, of Port Jackson shark (*Cestracion philippi*). British Museum (Natural History).

of the sharks in the Mississippian, when they were the dominant marine fishes, and a quick decline immediately afterward, the history being the same in Europe. These sharks were nearly all of primitive types, that is, the acanthodians were least in number, and by far the commonest were those with pavement-like teeth, known as cestracionts, and the cochliodonts (Fig. 406). The acanthodians (defined on the next page) vanished with the Paleozoic, while the other forms were very sparingly represented after Permian time.

The modern sharks appeared in the early Mesozoic and were common in the Cretaceous, attaining their climax in the Miocene, but the stock was greatly reduced by the cold waters of the Glacial period.

The *acanthodian* (*spinous*) *sharks*, which were of small size, rarely exceeding a foot in length, are particularly common in the Old Red deposits of Scotland, but are also known in Paleozoic marine strata since the Upper Silurian (see Pl. 14, Fig. 1). They are differentiated from the true and most other Paleozoic sharks by their placoid skin, in which are embedded small, flattened, closely fitting, bony plates composed of dentine and enamel, and by the further fact that the stout spines are not restricted to the median fins but are also developed in connection with the paired fins. The teeth are small and rather of the pointed type like those of modern sharks.

The term *Selachii* is taken from the Greek and means *sharks*. The order includes the large, active, more or less spindle-shaped sharks, the saw-fishes, and the flattened, sluggish, bottom-living rays and skates of the present time

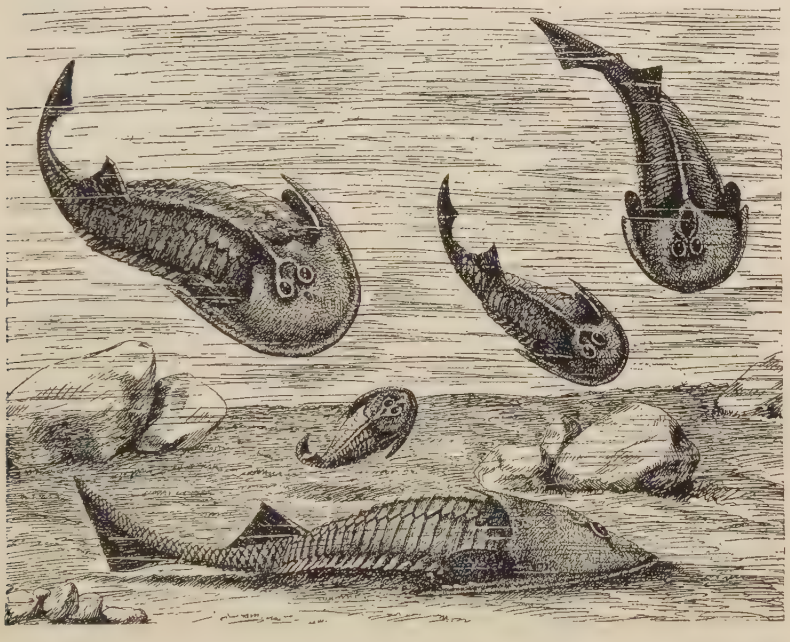


Fig. 407. — Small armored fishes (Ostracodermi) restored (*Cephalaspis*). Lower Devonian of Europe. After Koken, from Museum Guide of University of Tübingen.

and of the Tertiary and Mesozoic eras. The Paleozoic forms of this order are the two families known as cestracionts and cochliodonts. The first group is best represented by the Port Jackson shark, which lives off South Australia (see Pl. 14, Fig. 3), and is characterized by having two stout dorsal fin spines and, in the deeper parts of the mouth, many blunt and pavement-like teeth adapted for crushing shellfish and crustaceans (therefore also known as the "oyster crusher"). In the cochliodont sharks the individual teeth are fused into two large plates whose upper surface has spirally curved ridges suggesting the spirals of snail shells, the characteristic that gave rise to the family term (see Fig. 406). It is these hard parts that are so often seen in the later Paleozoic and far

less commonly in the Mesozoic; the cochliodonts, however, vanished with the Carboniferous. The sharp-cutting type of tooth seen in modern sharks was not common in the Paleozoic, but since the Cretaceous it has been abundant. In the Miocene of South Carolina occur teeth of this type, the largest of which are nearly 6 inches in length (*Carcharodon*), indicating sharks with a length of 60 feet. The living Great Blue Shark attains to 40 feet in length.

Subclass Ostracodermi or Bony-skinned Fishes

The small group of ostracoderms (means *bony-skinned*), or armored and possibly highly aberrant sharks, lived only during the Ordovician, Silurian, and Devonian periods, and represent a line of

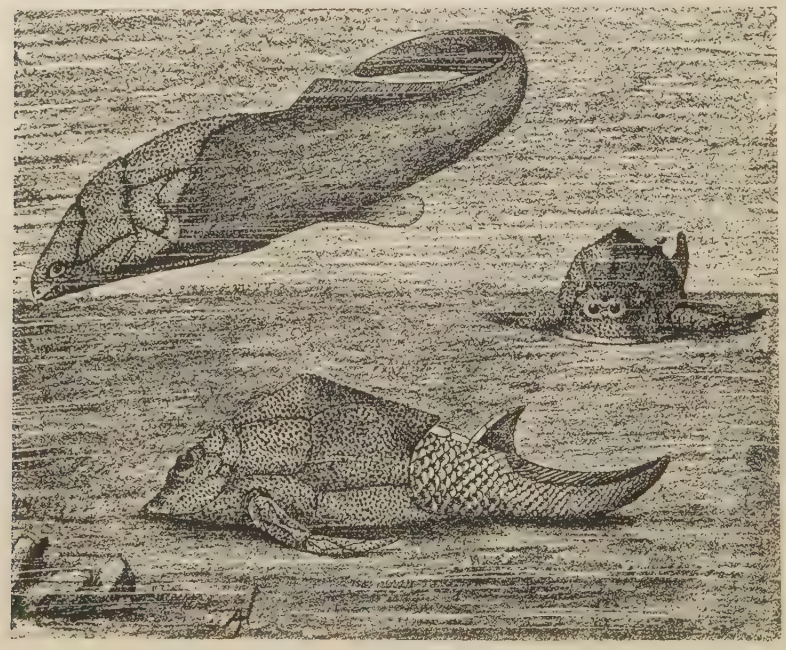


Fig. 408. — Devonian armored fishes (Ostracodermi), having a pair of swimming paddles (*Pterichthys*), shown in the two lower figures. The upper figure is an armored marine lung-fish (*Coccosteus*), one of the Arthrodira. After Koken, from Museum Guide of University of Tübingen.

fish evolution in the wrong direction, for they have left no descendants. They are, in fact, so different from other true fishes as to make it impossible as yet to indicate their relationship to other vertebrates. The subclass includes the oldest known fishes and is thought to be a highly aberrant stock of cartilaginous sharks. The ostracoderms were probably bottom-feeders and of sluggish habits, apparently living in the lagoon areas of the seas and in the

rivers. The head and anterior body was large, broad, and depressed, and armored by small placoid plates or scales, which were sometimes fused into more or less thick bony plates, while the posterior region was either naked or more or less covered by similar plates or scales. The tail was heterocercal, and there was no internal skeleton (see Figs. 407, 408).

In structure and form, there was considerable variety among the bony-skinned fishes. The older kinds, of very diverse construction, were without a pair of lateral paddles or swimming limbs (*Pteraspis, Cephalaspis, Drepanaspis*), and the eyes were either far apart or set closely together (see Figs. 407, 408). Restricted to the Upper Devonian, and probably to fresh waters, occur the forms with anterior armored paddles, decided armor over the anterior region, and eyes closely set (*Bothriolepis, Pterichthys*, Fig. 408). It is possible, however, that the latter genera do not belong in this subclass. The ostracoderms are widely distributed throughout Europe and North America.

Subclass Dipnoi or True Lung-fishes

The Dipnoi (from the Greek words meaning *double breathing*) are the "lung-fishes," so termed because the three living genera have an air bladder which opens into the mouth and which is either single or double, with numerous cellular spaces. This is an outgrowth of the anterior region of the digestive tract and serves as a lung, supplementing, and in times of drought supplanting, the functions of the gills as organs of respiration. From an evolutionary standpoint, the lung-fishes are very important, because the air bladder is comparable with the lung of the higher vertebrates in that it returns the aërated blood direct to the heart, whereas in most other fishes the blood is carried from the air bladder through the general circulation before reaching the heart. The nasal sacs are on the exterior of the snout and open into the mouth, a condition met with also in Amphibia and higher vertebrates, but very rarely in fishes. It is in the lung-fishes, then, that we see the possibilities for the development of the higher vertebrates, though this does not necessarily mean that they were the progenitors of the latter. In many ways, they are intermediate in structure between the lower fishes and the amphibious salamanders, but they are not the connecting links between the fishes and the amphibians. It is probable that paleontologists will discover in the older Devonian, or possibly even in the Silurian, the stem animals that gave rise on the one side to the lung-fishes, and on the other to the salamander-

like Amphibia known as Stegocephalia. This evolution is further discussed in Chapter XXXIX.

The dipnoans (Pl. 14, Fig. 4) are sluggish animals, rising occasionally to the surface for a new supply of air; in times of drought they encase themselves in a cocoon made of slime and clay, and breathe air through an opening made in the mud. In this condition, and without food, some can live for eight months. In the living forms there are also either two or four pairs of gills covered by a movable bony operculum. They are generally eel-like in appearance, with the dorsal and ventral median fins usually continuous with the tail fin. Among the Devonian forms the tail is usually of the heterocercal type (Pl. 14, Fig. 5), but in recent forms it is diphycercal (Fig. 4). The paired fins are long, broadly lobed, muscular, scaled, and fringed in the Devonian species and in living *Ceratodus*, but in other modern forms they are very slender, pointed, and without the fringe. The body is covered with overlapping *cycloid* scales, that is, thin, elastic, circular plates of phosphate of lime, but without enamel.

Dipnoans are cartilaginous fishes in which there is, however, some ossification, but they have no vertebræ differentiated as such. The skull consists of cartilage covered by a variable number of membrane bones that are thickest in Paleozoic genera. These are superficial bones developed in the membrane covering the cartilage, and are not formed in the cartilage itself. The teeth are few in number, usually in three pairs, of which two sets are large crushing plates. The food consists in the main of crustaceans, shellfish, frogs, worms, and insects, along with water plants. The intestine has a spiral valve similar to that in elasmobranchs.

The dipnoans are closely related to the fringe-finned ganoids (see page 690), these two types of fishes being the most important offshoots of the primitive sharks. The oldest dipnoans, in about fifteen species, occur in the Devonian of both Europe and America.

Subclass Arthrodira or Armored Fishes

The term Arthrodira means *jointed neck*, and is given because the armor of the head slides somewhat over that of the body, thus allowing the head to move up and down, a rare feature among fishes, seen only in this class and among the bony-skinned type (Figs. 408, 409). Arthrodira were more or less heavily armored animals whose relationship to the other fishes is unknown. The great majority were marine, the group having gone to sea from fresh water before Devonian time. In America they were the

largest and fiercest fishes of this time, but died out in the earliest Mississippian. They had no true teeth; the structures functioning as such were large cutting shears or crushing plates and were few in number. The tail was heterocercal and there appears to have been a pair of pelvic fins. Of an internal skeleton there was little, for

Fig. 409. — The "terrible fish" (*Dinichthys*), an arthrodire from the Upper Devonian of Ohio. *sl*, sliding joint, the feature that gave rise to the name Arthrodira. Original in American Museum of Natural History.

the vertebral axis was not bony, though the neural and ventral arches were somewhat ossified.

The Arthrodira easily dominated the aquatic life of the Devonian seas, one American form, *Dinichthys*, the "terrible fish," attaining a length of over 20 feet (Fig. 409). There are more than forty species known in North America, and one locality in Germany (Wildungen) has alone yielded upward of fifty forms.

Subclass Ganoidei or Enamel-scaled Fishes

The term Ganoidei, which means *bright appearance*, has reference to the glossy surface of most of these fishes, as, for instance, in the living gar-pikes (see Pl. 13, Fig. 1). This glossiness is due to the more or less thick rhombic scales found in gar-pikes or the cycloid-like scales in Devonian forms, which are covered with bright enamel of the same character as the outer covering in teeth. The ganoid scales differ from the placoid scales of elasmobranchs in that they have but two layers, an outer enamel and a thicker bony layer beneath. In some ganoids, however, there are true elastic cycloid scales (see Pl. 13, Fig. 4). The ganoids are essentially fresh-water fishes, although some are marine and only ascend the rivers to spawn. In the geologic past the marine members seem to have been considerably more common than now. The best known living examples are the sturgeons and gar-pikes, but the origin of the subclass goes back at least to the Lower Devonian, for they are common in the Old Red sandstone (see Pl. 13, Figs. 2–4)

and continue to be abundant until early Cretaceous time. In their organization they form a connecting link between the sharks and the bony fishes.

The skull is well protected by dermal bones or is completely ossified, and while the interior skeleton is more or less bony, there are some forms in which it is wholly cartilaginous. In this subclass appears for the first time the perfected fish mouth, in which the lower jaw operates against the teeth of the perfected upper jaw, as in the higher vertebrates. An air bladder is always present and is connected with the gullet; in the gar-pikes it assists in respiration but is never cellular as in the lung-fishes. There is a spiral valve in the intestine, and the tail is heterocercal or diphycercal.

Fringe-finned Ganoids. — According to the character of the fins, the ganoids are divided into two orders, namely (1) the fringe-finned or lobe-finned ganoids (Crossopterygii), and (2) the pillar-finned ganoids (Stylopterygii). Those of the first order are essentially fresh-water fishes and have thick, muscular, scale-covered, lobe-like limbs fringed with a marginal membrane as in some lung-fishes. Of this order there are but two genera, both of which live in the fresh waters of Africa. Even though their air bladder also functions as a lung, these fishes cannot live out of water more than three hours. They were the common fishes in the Lower Devonian, the best known forms being the genera *Holoptychius*, *Eusthenopteron*, and *Osteolepis* (Pl. 13, Figs. 2–4). In these ganoids the layers of bone of the conical teeth are often deeply and complexly folded or labyrinthine, and in this are particularly interesting because the same kind of teeth occur in all of the Paleozoic amphibians. This similarity of tooth structure is another hint showing the common origin of the Devonian fresh-water fishes and the Amphibia.

Pillar-finned Ganoids. — The more modern or pillar-finned ganoids differ from the fringe-finned forms in that the limbs have not the thick, muscular, scale-covered lobes, but are more like those of the higher or bony fishes. They also occur in the Devonian but are the rarer forms of ganoids in the Paleozoic. In the marine deposits of Mesozoic time, and especially of the Jurassic, they occur frequently.

Subclass Teleostei or Bony Fishes

The teleosts (means *true bone*) are the modern fishes and express the highest organization among these animals, for their evolution has tended to complete adaptation to the water (see Fig. 404). Most of the fishes of commerce and sport are of this subclass and occur abundantly in the fresh waters, seas, and oceans. Their origin was in the Ganoidei, apparently in late Paleozoic time, but they were not common until the Comanchian, with their best development in the Tertiary and at present.

The bony fishes are nearly always covered with thin, elastic, cycloid scales, never with placoid, and very rarely with ganoid

scales. In some the skin is naked and slimy. The caudal fin is usually homocercal and the paired limbs are never lobed. The gills are always covered by a movable operculum. The elongated air or swimming bladder, when present, is filled with gas and lies dorsally to the body cavity; it is not a lung but a hydrostatic organ. The internal skeleton is wholly ossified, the vertebræ are hollow at both ends (amphicœlous), there is a bony neural arch enclosing the spinal nerve-cord, and each vertebra has also a pair of ribs enclosing the viscera. Many of these characters are also seen, but less perfectly, in the Ganoidei, and therefore some naturalists regard both subclasses as representing but a single group.

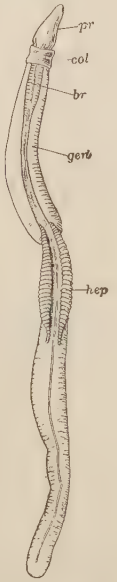


Fig. 410. — The worm-like half-vertebrate *Balanoglossus*, from the dorsal side. After Spengel. *br*, branchia or gills; *col*, collar; *gen*, genital ridges; *hep*, elevations formed by liver lobes (cæca); *pr*, digging proboscis.

Ancestry of Fishes

In spite of the facts that fishes have bony skeletons and that they are known back to the Ordovician, their early ancestors are still undiscovered. Zoölogists are not able to determine this ancestry even among the vast horde of living forms and their embryos, nor have paleontologists, on the other hand, as yet found the "missing links" between the invertebrates and the fishes. The oldest fossil vertebrates are undoubted fishes, seemingly of elasmobranch character, and, while the paleontologist may yet find vertebrates of a lower type, it seems as if the natural conditions are against this possibility, because the earliest vertebrates must have been not only small but also without hard parts.

Among the unsegmented worms (nemertians) one finds the closest approach to the lowest type of vertebrate ancestors in animals often spoken of as half-vertebrates (Hemichordata). The structural gap between them is, however, great. The Hemichordata are worm-like animals, with a distinct head and tail, and breathe through the anterior region of the intestine (intestinal breathers). In this group we see in *Balanoglossus* the rudiments of the future gills, the breathing organs of fishes (see Fig. 410). Further, the main nerve-cord is situated dorsally and the intestinal tract ventrally, and these

are the fundamental structures around which the vertebrate organization has been evolved.

Balanoglossus burrows in sand and mud in almost all seas and attains a greatest length of 6 inches. The anterior end is formed of the burrowing proboscis, beneath which on the ventral side is the mouth, followed behind by the collar, then the region of gill slits, and finally a long, soft, slightly coiled portion. There is a dorsal nerve-cord, often tubular, and like a typical spinal cord. The dorsal region of the pharynx is respiratory and the water passes through the gill slits, which open dorsally on the exterior. These gill slits have chitinous skeleton bars.

The next step is seen among the sea-squirts (tunicates). These animals, however, are greatly degenerate in adult life, due to their sedentary habit, and their vertebrate affinity is only shown in the earliest stages of growth (see Fig. 411). They are on the border line between the invertebrates and vertebrates. Their tiny larvæ are free and active animals, strongly resembling the next higher known stage in vertebrate evolution, the lancelets, described below. What is so important in the larvæ of the sea-squirts is that they have in addition to the hemichordate structures a true notochord in the tail, the notochord being the rudiment out of which the vertebrated backbone of the higher vertebrates has evolved. Sea-squirts are therefore spoken of as primitive chordates (Urochorda), that is, vertebrate animals with the most primitive type of backbone, which, however, is not bone, nor even cartilage, but a gelatinous unsegmented material. The spinal cord or trunk nerve lies above or dorsally to the notochord.

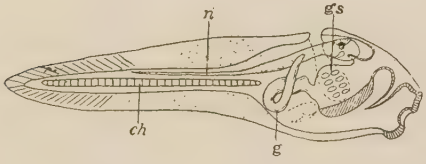


Fig. 411. — Sectional diagram through a tunicate embryo (*Clavellina*). Modified from Seeliger. *ch*, notochord; *g*, gut; *gs*, gill slits; *n*, nerve-cord beginning to degenerate.

The larva of a tunicate is not unlike the lancelet and has a dorsal nerve-cord, a notochord in the tail region, gill slits opening from the pharynx, a branchial chamber that in turn opens into an external aperture, and an eye developing from the brain. In its development the promise of youth is unfulfilled; the active larva settles down to a sedentary life, loses tail and notochord, nerve-cord, and eye, and becomes strangely deformed.

Lancelets (lance-shaped) represent the third great step toward the perfection of the vertebrates, but are an offshoot from the main line of ancestors to the fishes. Nevertheless, they are "a prophecy

of a fish " and in them the notochord is well developed as a cylindrical rod of notochordal tissue. However, it is not yet cartilaginous (see Figs. 412, 413). From the lancelets to the cyclostomes,

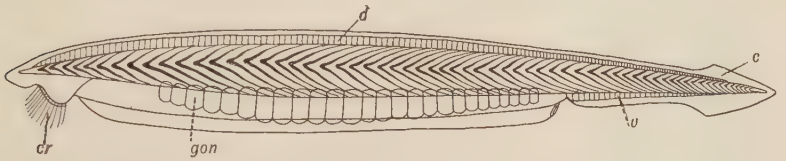


Fig. 412. — The lancelet (*Amphioxus lanceolatus*), " a prophecy of a fish." After Lankester. *c*, caudal or tail fin; *cr*, sensing cirri around mouth; *d*, dorsal median fin; *gon*, gonads or reproductive organs, as seen through the transparent body; *v*, median ventral fin. The V-shaped markings show the exterior muscles.

practically all of the many intermediate evolutionary steps are lost. Similarly, many steps are lost between cyclostomes and the true fishes.

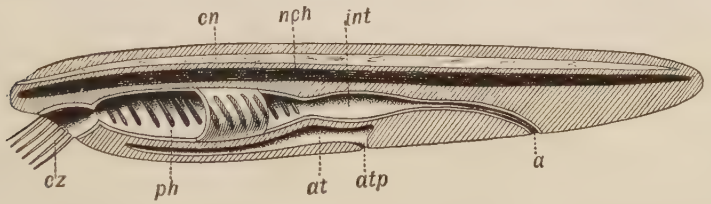


Fig. 413. — The lancelet sectioned to show the internal parts. From Boas's *Lehrbuch*. *a*, anus; *at*, atrium or passage into which the water passes from the gills and then passes out at the atriopore (*atp*); *cn*, central nerve or spinal cord; *cz*, cirri around vestibule that opens into mouth; *int*, intestine; *nch*, notochord; *ph*, pharynx, seen from inside and outside, through which pass the gill slits.

Lancelet or Amphioxus. — In the living world there are about sixteen widely distributed species of lancelets living near the coasts in warm and temperate seas, but no fossil lancelet is yet known. These are vertebrates reduced to the very lowest terms. The animals are sluggish in habit, living somewhat buried in the sand, and ranging in length from 0.5 to 4 inches. They feed on microscopic organisms or organic particles.

In general form these little animals are fish-like, but they are widely removed from the fishes by the absence of limbs, skull, jaws, differentiated brain, eyes, definite heart, spleen, and genital ducts. There is, however, a tubular dorsal nerve-cord, the notochord being persistent, unsegmented, and surrounded by a continuous sheath. The gill slits are very numerous and in the adult there may be as many as one hundred pairs. There is a median dorsal and ventral fin continued around the diphycercal tail. On either side of the body there is a fold often interpreted as a fin fold.

Cyclostomata. — All of the fishes and the higher vertebrates as well are characterized by having articulating jaws, but there are other undoubted vertebrates without jaws which are lower in

structure. These are known as the Cyclostomata. This slightly diversified class includes the fresh-water lampreys and the marine hag-fishes (see Pl. 13, Fig. 5), animals sometimes confounded with the eels (true fishes), though the resemblance between them is only in the general form of the body. They are without jaws and paired limbs, and the skeleton is wholly cartilaginous, except the horny teeth, which are set in the mouth in circular and radiating rows (see Fig. 414). The gills, usually seven in number, are in pouches, the external and internal openings being small.

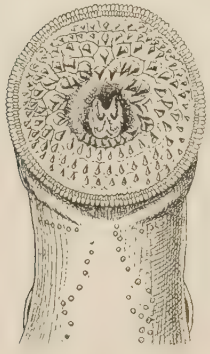


Fig. 414. — Mouth of the lake lamprey, showing rasping teeth, and larger teeth of central tongue. After Gage.

It is not probable that the cyclostomes are in the direct line of evolution to the fishes, but they give at least a good hint of the probable fish ancestors. They are the lowest vertebrate stock with skulls, the lowest class of the subphylum Craniata. The oldest form, if a true cyclostome, occurs in the middle member of the Old Red at Caithness, Scotland

CHAPTER XXXVIII

DEVONIAN TIME AND THE DOMINANCY OF THE FISHES

History of the Term Devonian. — Previous to 1833 the geologic column was not determined beneath the "Carboniferous," the time of the world's greatest coal making. In western Europe, however, it was soon noted that above the coal-bearing strata there lay a great mass of red sandstones and marls, and that beneath the Carboniferous in Scotland occurred a similar mass. Because geologists had not yet recognized the importance of designating type areas of strata by the name of the locality in which they occur, these two divisions came to be known simply as the New Red sandstone (upper series) and the Old Red sandstone (lower series), with the Carboniferous between them. The upper series, because in Germany it has three divisions, was later named Trias, a term now altered to Triassic, but the Old Red sandstone, on the other hand, to this day has failed to yield undoubted marine fossils, and since the geologic column is essentially based on a marine faunal sequence, this lower series did not bear in itself the evidence for correlating it with marine beds. However, not far away from the Old Red area of Scotland, in Devonshire, southern England, there had been collected a number of fossil corals; these were placed in the hands of Lonsdale, and he, in 1837, expressed the opinion that they were intermediate in character between those of the Silurian and the Carboniferous, and, further, that the limestones of Devonshire were of the age of the Old Red sandstone.

This important information was imparted in the same year to both Murchison and Sedgwick, geologists to whom we owe, as has been said in earlier chapters, the first determination of the actual sequence of the Paleozoic strata beneath the Carboniferous. In 1839 these two workers concluded that certain of the marine strata of Devonshire were in all probability the equivalent of the Old Red, and that they occupied a stratigraphic position between the Silurian and the Carboniferous, so, fearing that the New York state geologists would soon propose a period name for equivalent formations, they hastened their work, and in the same year defined the period term Devonian. In the type area in southwestern

England to this day the base of these rocks is not to be seen, and a worse region for the erection of a period term could hardly have been selected. The Devonian here was seen eventually to consist of an immense series, 10,000 to 12,000 feet thick, of graywacke, slate, and limestone, with intercalated eruptives and beds of tuffs. All these are decidedly folded and very much faulted, so that the stratigraphic sequence could only be made out on the basis of the equivalent strata of the continent of Europe. This inherent difficulty was soon recognized by Sedgwick and Murchison, and they crossed the channel and began work in the Rhine valley of Germany, where there is one of the best known developments of Devonian faunas. Their results on this area were published in 1842, but although nearly all the strata studied by them are now recognized as Devonian, at that time they referred most of the rocks to the Cambrian and Silurian. In practice, all Devonian correlations are still made with the Rhine area, although the period name is based on the sequence in Devonshire. If our English cousins had waited until 1842, this period would now be called Erian, and the state of New York would be the type area, than which there could have been no better, even in Germany.

American Devonian

The strata making up the Devonian system in North America have a very wide distribution, especially those of the Middle Devonian, the Lower Devonian rocks being restricted to the margins of the continent (see Pl. 15). Because of this distribution, the Devonian strata of the interior of the continent are, by their faunal content, readily distinguished in the field from the Silurian, but their separation from the Carboniferous above in the Mississippi valley is not so easy. In this interior region the strata are all conformable upon one another, and the disconformities separating the systems can, as a rule, only be determined by the aid of the faunas (see Fig. 415). In the Ohio and Mississippi valleys also the Devonian often terminates in a black shale series and the Mississippian system as often begins with a very similar formation (see Fig. 369). Almost nowhere are there angular unconformities between them.

The longest sequence and the thickest series of Devonian deposits occur in the northern Appalachian area, where most of the materials are shales and fine-grained sandstones. The Catskills on the west side of the Hudson River are the most imposing single Devonian pile in the United States. Another fine Devonian section occurs

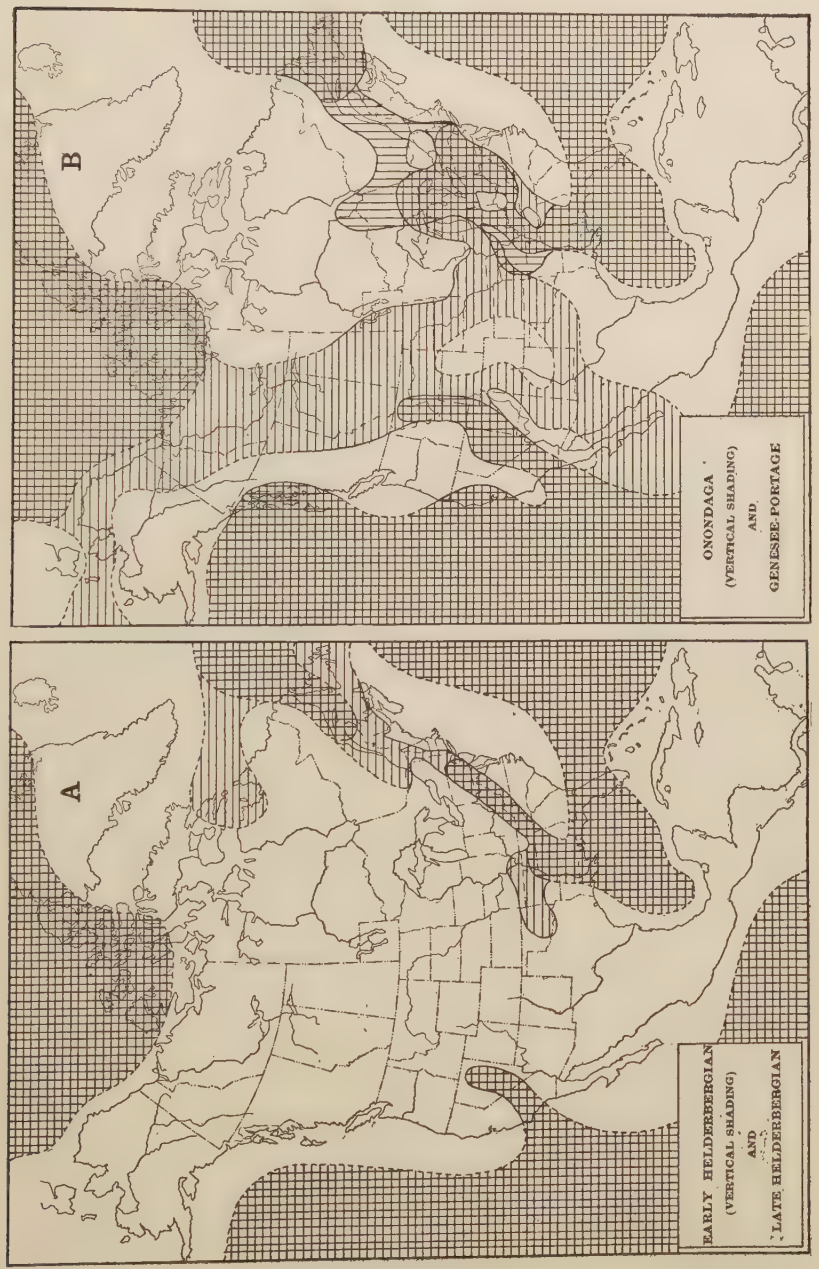


Plate 15. — Devonian paleogeography.

at Gaspé on the end of the peninsula bordering the St. Lawrence River on the south, where the basal 2000 feet of limestone, of Lower Devonian time, are followed by 7000 feet of Middle and Upper Devonian sandstones. Elsewhere in the Maritime Provinces of Canada and in the New England States, the Devonian is poorly represented, and when present consists almost entirely of continental deposits. In the region of the former Cordilleran sea of the United States these formations are never prominent except in Nevada, where, in the Eureka district, a thick section of them is found. In the area of the Canadian portion of this sea there is a good de-

Fig. 415. — Devonian-Silurian disconformity, Buffalo, N. Y. The Middle Devonian (Onondaga) limestone rests on the Silurian (Manlius); below is shown another break (Manlius-Bertie).

velopment of Middle and Upper Devonian, not only in the western mountains but especially to the east of the Cretaceous deposits in the Mackenzie valley and in Manitoba.

Devonian Localities. — The Devonian strata may be seen to good advantage in the Catskill Mountains of eastern New York, and for 25 miles west of Buffalo along the shore of Lake Erie in the western end of the same state (see Fig. 415). About Cumberland, Maryland, almost the entire New York sequence is repeated. Cleveland, Ohio, stands on Upper Devonian, and Sandusky and Columbus, also in that state, on Middle Devonian deposits. Louis-

ville, Kentucky, is famous for its Middle Devonian coral reef. Milwaukee, Wisconsin, and Davenport, Iowa, are good places for fossils of this period. In Michigan, at the summer resort Petoskey, and more especially at Alpena, and in western Ontario about Thedford may be found especially fine Middle Devonian organisms.

The Devonian system in New York is the best known and is therefore the standard for reference in correlation. It is divided as follows:

Upper Devonian	Chautauquan	Chemung-Catskill groups
	Senecan	Portage-Naples-Ithaca groups
		Genesee-Tully groups
Middle Devonian	Erian	Hamilton group
		Onondaga group
Lower Devonian	Oriskanian	Esopus-Oriskany groups
	Helderbergian	Becraft-New Scotland-Coeymans formations

Movements in Appalachia and Acadia. — The great southeastern land Appalachia appears to have been elevated somewhat during the Oriskanian, with more rapid erosion, for there is considerable sand in the deposits of this time in southeastern New York, Pennsylvania, Maryland, and West Virginia, which became coarser as time progressed. Finally, during the earlier part of Onondaga time, some land was added along western Appalachia as a foreland, but all of it was resubmerged before Hamilton time. From this evidence it is thought that, while Appalachia was moved somewhat during the Lower Devonian, the movement was not of a marked character, and the land remained a lowland throughout this period.

Shickshockian Disturbance. — The Acadian mass, however, throughout the New England States and the Maritime Provinces of Canada, began to be moved, that is, elevated and folded, in Middle Devonian time, and the sea was finally completely drained throughout the entire area, destroying forever the seaways that formerly connected the Central Interior sea with the St. Lawrence trough. This movement continued to the end of Devonian time, since even the Upper Devonian strata, of continental character, are folded. Throughout the Devonian, and especially in the Upper Devonian, volcanic activity occurred here on a large scale, many of the intruded masses being still preserved in the Maritime Provinces. Mount Royal, back of McGill University, Montreal, and the Monteregian hills to the east are volcanoes of this time, but far greater intruded masses are seen in many places throughout New Brunswick and southern Quebec. The igneous masses of the Shickshock Mountains along the northern sides of the peninsula of

Gaspé are of that time, and possibly also the crystalline rocks of the White Mountains of New Hampshire. With this folding, the rivers of Acadia were rejuvenated and erosion was marked during Devonian time, for the detrital materials (muds and sands) now piled up in eastern Pennsylvania and New York with, in places, a thickness of nearly 13,000 feet, are the erosional products of this elevation. In Acadia itself the deposits of later Devonian time are of the continental or Old Red sandstone character and contain land plants and fresh-water fishes.

According to Dawson, throughout Nova Scotia, New Brunswick, and southern Quebec the Carboniferous formations rest with marked unconformity upon the older rocks. This being so, the Acadian disturbance was of greater import than is usually believed by American geologists. This deformation was named Shickshockian by Schuchert in 1914.

In the interior of North America the land was variously warped, but all of the movements were of small amount, and resulted only in making very shallow basins for the Middle and Upper Devonian submergences.

During the Lower and Upper Devonian there was also much volcanic activity throughout western Europe, in Great Britain, western Germany, France, and elsewhere.

Submergences of the Continent. — At the beginning of Devonian time almost all of North America had emerged, and at no time during the Lower Devonian was more than 10 per cent of the continent covered with marine waters (see Pl. 15). The Devonian seas were long and narrow in the Appalachian, Acadian, and Cordilleran geosynclines, the invasion from the Gulf of Mexico lying to the south and west of the Cincinnati uplift and south of the Ozark mass. The waters appear to have been oscillatory and unstable in areal extent, and this is especially true of the Appalachian trough.

Late in Oriskanian time the submergence became markedly positive, and attained its maximum flood in the late Middle Devonian (Hamilton), when at least 38 per cent of North America was covered by the sea (see Pl. 15). The waters spread from the Gulf of Mexico northward along the western side of the Cincinnati uplift and across northern Ohio, united with the Atlantic flood, and the two then spread northward from Michigan into the country of James Bay, an extension of Hudson Bay. The waters were warm, for they brought many coral species which built extensive reefs seen in many places in the limestone deposits. There was also an

Arctic invasion through the Cordilleran sea, but when its flood is compared with that of Silurian time it is seen to have been greatly reduced in width, for there was now no inundation throughout the Hudson Bay region and for a long distance northward, as was the case during the two previous periods. The northern water also had an abundance of corals, this being particularly true for Alaska.

Probable Cause of Submergences. — The great Middle Devonian flood was also common to Europe, Asia, South America, and Australia, the strata in New South Wales alone having a thickness of 10,000 feet. It was one of the greatest of continental inundations, exceeded by only one of the subsequent floods, that of Cretaceous time. Such a flooding of the lands could not have been wholly due to the unloading of the eroded land materials into the oceans, for it was of too great an areal extent. Previously, however, when discussing the Caledonian Disturbance of Silurian time, it was stated that Laurentia and Baltica were welded into one continent by that movement, and it is probable that the shallow pre-Devonian sea lying between Britain, Norway, and Greenland was also destroyed at that time. It is true that this elevation began toward the close of the Silurian, but that it continued into early Devonian time is attested by the marked and long-enduring volcanic activity in Acadia and western Europe. Not only this, but the extremely thick deposits of the Old Red, to be described later, were accumulated in mountain valleys during and immediately after this upheaval, and are further evidence to the same end. Therefore, the displacing of the Norwegian sea by an extensive land area, combined with the unloading of the mountains into the oceans, caused the general water level to rise everywhere and thus brought about the marked inundation of the continents in Devonian time.

Emergence of the Continent. — During the Upper Devonian the seas were gradually withdrawn, first in the southern Mississippi valley and finally throughout the interior of the continent and the Cordilleran area. If there was any water left on the land, geologists have as yet failed to discern its transition strata uniting the Devonian to the Mississippian. Thus nature delimited another geologic period in the history of the earth, and at the close of the Devonian nearly all of North America was again emergent.

The Great Northern Transverse Continent Eria. — We have seen that the Caledonian Disturbance resulted in the making of mountains that extended throughout northwestern Europe. It was then that Laurentia (Canadian Shield-Greenland) was welded upon Baltica (Sweden-Finland), forming the most western part of the great

northern transverse land mass that extended unbroken far into Asia. Therefore, at the very beginning of Devonian time there came into existence an almost circumpolar land, whose only submerged portion lay in the North Pacific, and which was formed by the union of Laurentia, Baltica, and Angara (see Fig. 434). The great Canadian geologist, Sir William Dawson, of McGill University, labored long to make known the plant life of the Devonian, and since he termed it the Erian flora after the Erian rocks in which it is entombed, taking the name from Lake Erie and the Erie division of the New York state geologists, Suess in 1909 gave the continent the name of *Eria*. It is the old ancestral continent of the modern Holarctic region of the zoölogists (see Fig. 434).

Fig. 416. — Sir William Dawson (1820–1899). One of the founders of Canadian Geology.

Character and Thickness of Devonian Rocks. — *Eastern Lower Devonian Sediments.* — In the Appalachian trough from Virginia to New York the Lower Devonian sediments are well developed, with the most complete section in Maryland, of nearly 900 feet. About one half of these sediments in Maryland are limestones, while the rest are limy sandstones, grading more and more into pure sandstone toward the top. At the base of the Devonian and at the top of the Silurian, the impure magnesian limestones are often sun-cracked, showing the shallowness of these seas (see Fig. 417). Along the Delaware River in Pennsylvania the thickness is over 300 feet in the western area, but about Port Jervis, New York, the series thickens to 1150 feet, of which the upper 550 feet is grit (Esopus), and the rest limestone or calcareous shale. Northward into the foothills of the Catskill Mountains the Lower Devonian decreases rapidly, and only thin and scattered remainders occur west of Syracuse, New York.

Eastern Middle and Upper Devonian Sediments. — The sediments of Middle and Upper Devonian time in the Appalachian trough from southern Virginia north into the Catskills are of great thick-

ness and significance. The greatest thickness is in Pennsylvania, where the Susquehanna River has cut through the Appalachian Mountains; here the Pennsylvania Geological Survey has determined a maximum depth of nearly 13,000 feet of Devonian shales and sandstones, becoming increasingly coarser, redder, less marine, and more rapid in accumulation with the progress of time, that is, toward the top.

To make more evident what is represented in Pennsylvania, some of the details of the section should be given. In this great series, there are from 260 to 425 (Helderbergian 50–100, Oriskanian 210–325) feet of Lower Devonian limestone and arenaceous sandstone. The Middle Devonian starts with the widely

Fig. 417. — Sun-cracked Silurian limestone (Salina), Round Top, Maryland.

spread Onondaga limestone, which has a depth of 0 to 250 feet. Then begins the great detrital series of muds and sands, as follows: Hamilton, 1400 to 2500 feet; Portage, 1100 to 1400 feet; Chemung, 2200 to 4600 feet; and the Catskills, 2500 to 3700 feet. In other words, the Lower Devonian has 260 to 425 feet, the Middle Devonian 1400 to 2750 feet, and the Upper Devonian 5800 to 9700 feet, with most of it red shales and coarse sandstones and conglomerates. The thicknesses in Maryland are: Lower Devonian, 340 to 767 feet; Middle Devonian, 600 to 1650 feet; Upper Devonian, 4600 to 8550 feet.

Appalachian Delta. — Along with the greater rapidity of accumulation the marine faunas become increasingly scarcer upward in the section, and the sediments change in character to red beds,

most of which are of fresh-water origin, marked by ripples, sun-cracks, and rain imprints, and by land plants and land fishes. Pennsylvania was the central area of a great delta formed at the mouth of the large rivers that flowed out of the Acadian highlands, in which latter region there was mountain making and volcanic activity throughout much of the time of the delta accumulation. From this central and rapidly subsiding delta, the deposits thin rapidly to the north, west, and south, in the manner illustrated in Fig. 418.

Devonian Sediments of the Interior. — In the region of the Cincinnati uplift and throughout the Mississippi valley the essentially calcareous deposits, mainly of Middle Devonian time, are very thin when compared with those of the Appalachian region. At Louisville, Kentucky, the thickness is about 60 feet of Middle and 100 feet of Upper Devonian shales, and from here northward, both to the east and west, the sections thicken and introduce more shale, so that in western Ontario there is a depth of about 600 feet, much of which is shale. To the northwest, about Alpena, Michigan, the Middle and Upper Devonian sediments are still thicker, and there are here the greatest accumulations in the medial portion of North America.

In the southern Mississippi valley and in Oklahoma the Devonian sections are thin, and most of the deposits are of Lower and early Middle Devonian time. Probably no single section exceeds 250 feet.

Devonian Sediments of the Western and Arctic Regions. — In the Cordilleran sea the Devonian sediments were essentially limestones, and while the sections within the United States are usually less than 300 feet thick, yet in the Eureka district of Nevada there are from 4000 to 6000 feet of Devonian limestones and calcareous shales. The latter strata seem to represent an unbroken series from the beginning almost to the close of the Devonian period. In Manitoba there are about 400 feet of dolomites, limestones, and shales, and in the Mackenzie valley nearly 900 feet, of which about one half is limestone. From here northward the sections seem to thicken. In southeastern Alaska there are at least 600 feet of limestone. There is another area of sedimentary accumulation in the Ellesmere-Parry Island area, where Per Schei has published a Siluro-Devonian section with a thickness of 8000 feet, most of which consists of coarse Devonian detritals.

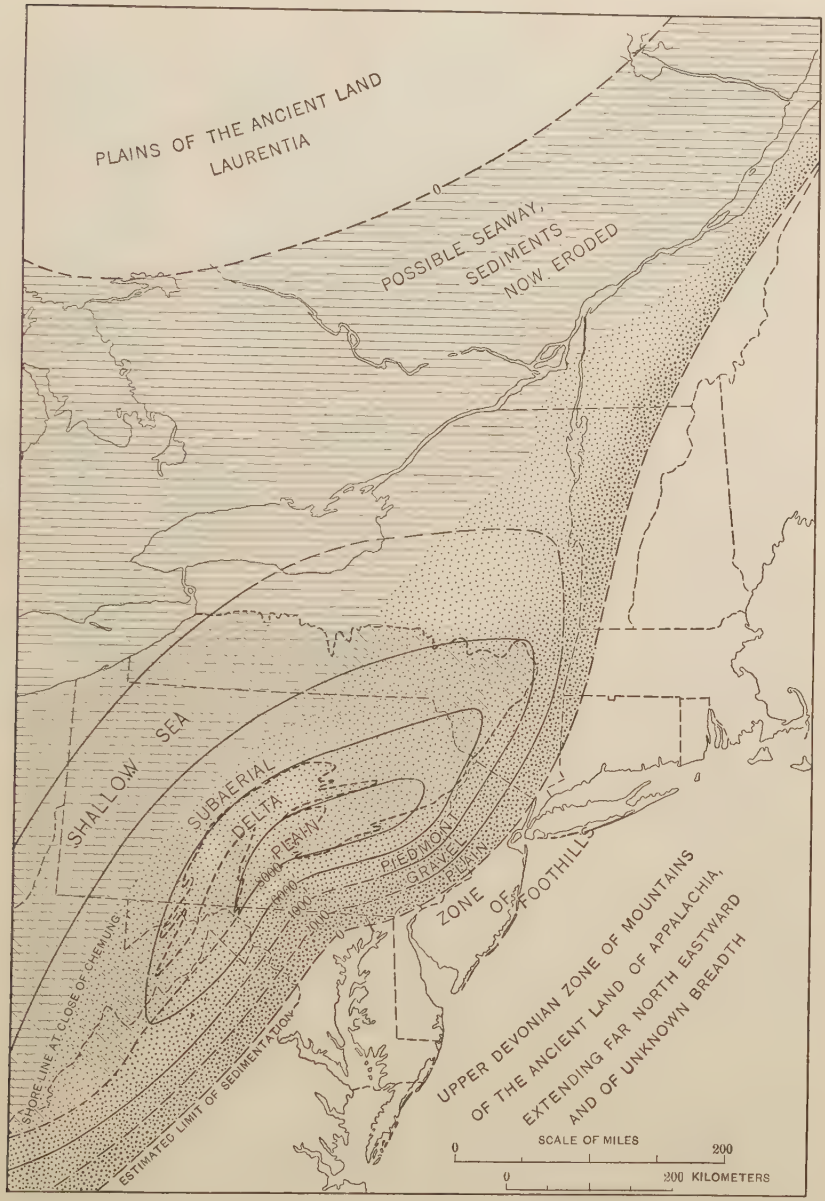

PLAINS OF THE ANCIENT LAND LAURENTIA
POSSIBLE SEAWAY, SEDIMENTS NOW ERODED
SHALLOW SEA
SUBAERIAL DELTA PLAIN
PIEDMONT GRAVEL PLAIN
ZONE OF FOOTHILLS
UPPER DEVONIAN ZONE OF MOUNTAINS OF THE ANCIENT LAND OF APPALACHIA, EXTENDING FAR NORTH EASTWARD AND OF UNKNOWN BREADTH
SHORE LINE AT CLOSE OF CHEMUNG
ESTIMATED LIMIT OF SEDIMENTATION
SCALE OF MILES
0
200
0
200 KILOMETERS

Fig. 418. — Devonian delta of the Appalachian geosyncline, as it probably was at the close of this period. Dotted area that of the fresh-water and brackish-water deposits; horizontal lines, marine deposits. Contours showing original thickness of Upper Devonian sediments. Diagonal lines, the area where the deposits still exist. Drawn by Barrell.

Life of the Devonian

Marine Provinces. — The American Devonian seas on faunal grounds may be arranged in three provinces. (1) In the Appalachian and Acadian areas the northern Atlantic waters dominated and the life was in harmony with that of northern Europe. This evidence is best seen in the Lower Devonian, where many species of the Rhine faunas occur, while throughout the balance of this period European migrants are only found periodically in the Appalachian trough. (2) The Central Interior sea to the west of the Cincinnati uplift was dominated by life that was characteristic of this area and of western Brazil, and it is sometimes referred to as the American faunal realm. There was, however, a great difference between the two hemispheres, for in South America corals were practically absent. (3) The Cordilleran sea was another faunal province with most of its life derived from the northern Pacific or Euro-Asiatic realm, and this biota was also wide-spread in the Arctic Ocean. This province was wholly independent of the Central Interior sea until near the close of Middle Devonian time, when the two seas had communication across Iowa and Michigan. The faunal intermigration, however, was most decided from the western to the eastern basin, and occasionally the bottom-dwelling forms migrated along the northern shore and attained western New York. In the Upper Devonian the faunas again took on a cosmopolitan character, the Euro-Asiatic aspect dominated most of the seas of this time, and its representatives are hence found in all three provinces.

Marine Invertebrates. — The seas after Middle Devonian time swarmed with corals, brachiopods, and shellfish, and in general the life was not very unlike that of the Silurian (see Pls. 16–18). The corals were wide-spread, and are known from Louisville, Kentucky, north into Alaska. The Louisville reef is the one best known; it has a great abundance of species, with cup-corals over 24 inches long and more than 3 inches wide, and compound colonies as much as 8 feet across (see Pl. 16). There were also many bryozoans, but the crinids were comparatively far less abundant and nowhere in America were they extensive makers of limestone, as they were in the Silurian. Of the echinoderm type of animals, the blastids were now common and may have originated in America (see Pl. 16). Starfishes were also at times abundant (see Fig. 419). Trilobites were still abundant, but greatly reduced in variety, there being about twenty genera and over one hundred species (see Pl. 18);

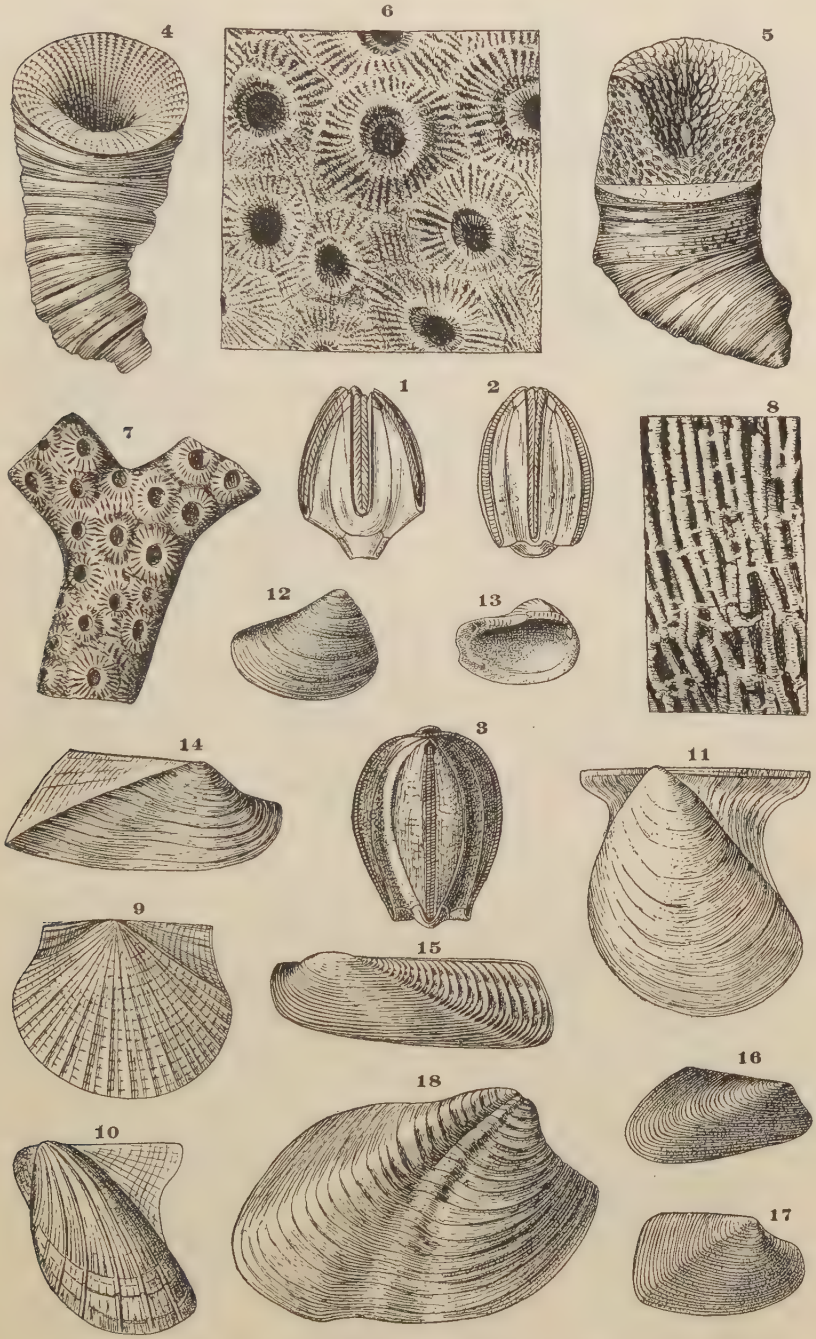


Plate 16. — Middle Devonian blastids (1–3), corals (4–8), and bivalves (9–18).
See Appendix B.

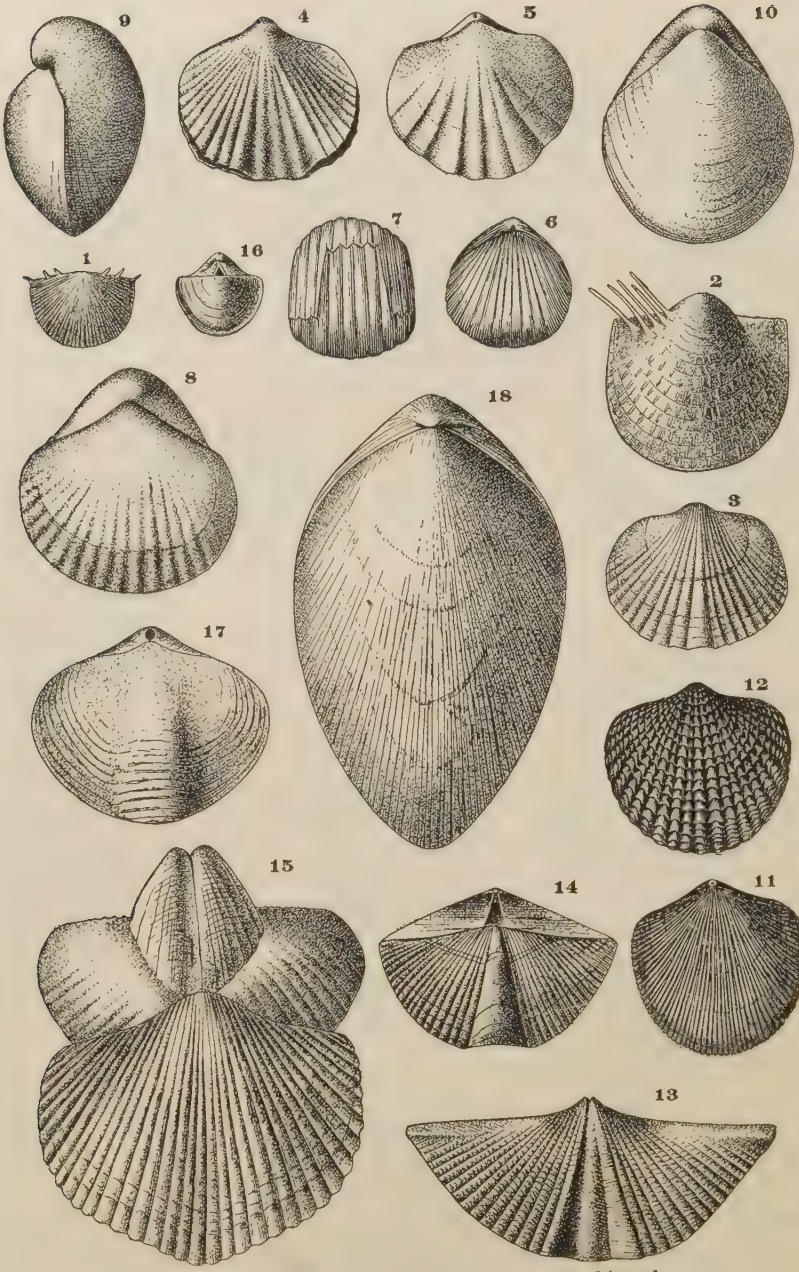


Plate 17. — Lower and Middle Devonian brachiopods.
See Appendix B.

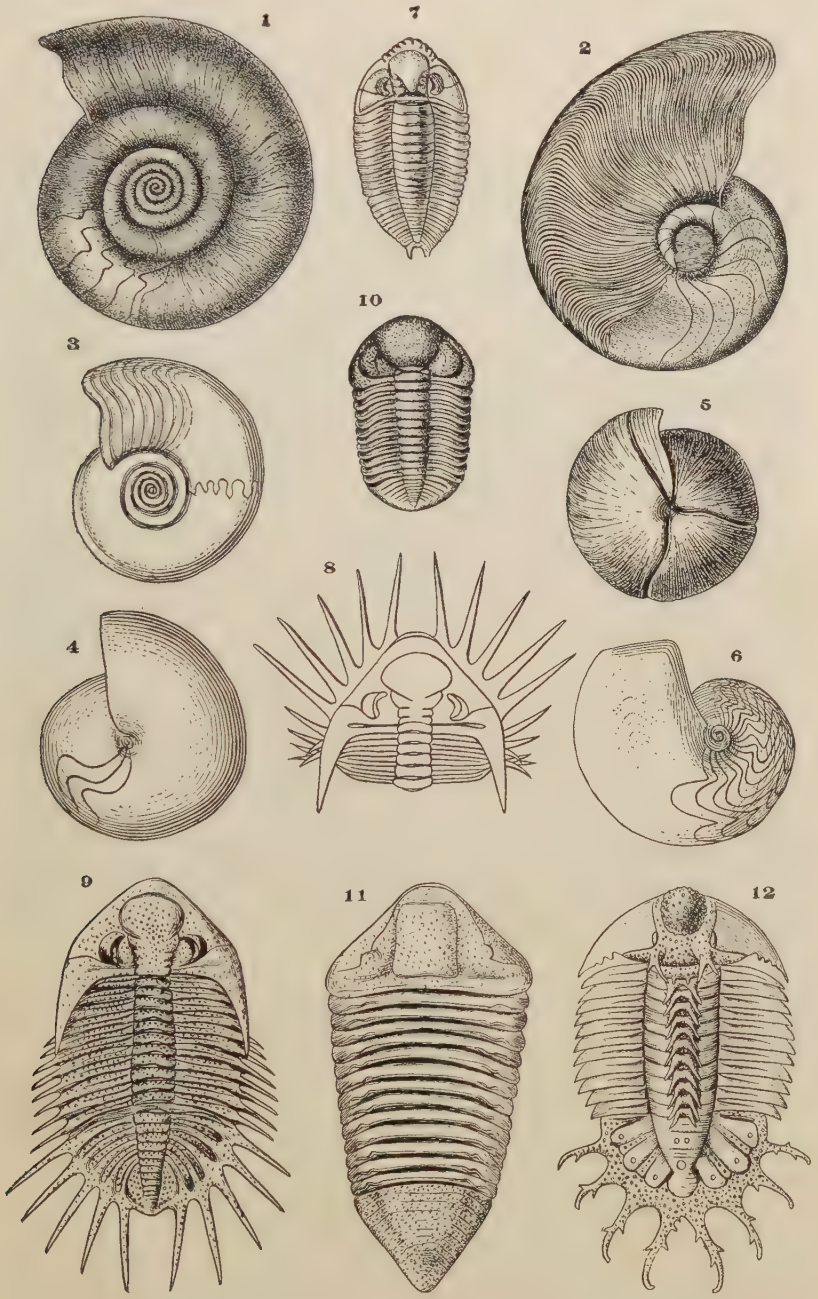


Plate 18. — Middle and Upper Devonian goniatites (1–6), and trilobites (7–12).
See Appendix B.

the most prevalent forms were the bullfrog trilobites (*Phacops rana*), the pointed-tail trilobites (*Dipleura*) and the spiny-tailed ones (*Cryphæus* = *Asteropyge*). The Devonian deposits are often full of brachiopods, of which there were no less than seven hundred

Fig. 419. — Middle Devonian sandstone slab, nearly 5 feet across, from Saugerties, N. Y., with about 200 starfishes (*Devonaster eucharis*) and clam shells (*Grammysia*). Original in New York State Museum, Albany. Photograph from John M. Clarke.

different kinds in North America (see Pl. 17). This was the time of their maximum development and differentiation. The most characteristic were the spire-bearing forms.

Comparing the American marine Devonian faunas with those of Europe, there is seen to be considerable dissimilarity, one especially marked difference being the development in the Old World of the goniatites (see Pl. 18). There these animals appear in six genera at the very base of the Bohemian Devonian and are usually prolific throughout the later part of the period. They continued to be

plentiful in the Mediterranean waters during subsequent Paleozoic time, but in America are usually rare fossils. Goniatites are cousins of the nautilids and gave rise in later Paleozoic time to the ammonids, the most characteristic marine animals of Mesozoic time. Goniatites are described in Chapter XLVIII.

Devonian Fishes. — The fresh waters of Devonian time must have abounded in life, an inference justified by the fact that more than one hundred species of fishes alone are known in the continental deposits of this time. As they are fully discussed and illustrated in the previous chapter, we need here only present a general summary of the Devonian kinds (see Pls. 13, 14). These fishes were primitive in that they did not have well developed internal skeletons, and in that these were more cartilaginous than bony. The median fins were often continuous, or a series of fins, extending along the dorsal and ventral surfaces and meeting around the end of the tail. The vertebral column often extended to the end of the tail, with the continuous fin all around it, a type of tail (diphycercal), nearly always present in the earliest stages of modern fishes. The heterocercal tail was the other common type.

The modern race of bony fishes, such as the perch, cod, and herring, which represent about 99 per cent of all living fishes, had not appeared; on the other hand, the tribe of sturgeons and gar-pike, now almost extinct, made up about a quarter of all Devonian forms; sharks, which are but a small percentage of all living fishes, made up about one third of all the kinds then existing; while, finally, the Arthrodira, a group long extinct and even of uncertain kinship, constituted 40 per cent of the ancient fish fauna. (Dean.)

The ancient marine sharks may have attained a length of from 5 to 6 feet in the Devonian, and dominated the seas of the next or Mississippian period, after which they rapidly declined to the end of the Paleozoic. With the rise of the marine fishes one notes the decline of the trilobites and the nautilids, and it is probable that the fishes fed largely upon both of these types of animals.

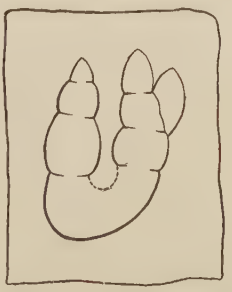


Fig. 420. — The oldest amphibian track (*Thinopus antiquus*). $\times\frac{1}{3}$. Upper Devonian of Pennsylvania.

Amphibia. — Of vertebrates higher than the fishes, the only evidence rests upon one foot imprint (*Thinopus antiquus*) nearly 4 inches long, which was found near the top of the Upper Devonian of western Pennsylvania (Fig. 420). This indicates the presence of a salamander-like

animal (stegocephalian) with a probable length of nearly 3 feet. The track is from a marine sandstone of the littoral or beach area over which the animal walked, probably in search of dead marine life. This stratum is associated with others that are ripple-marked and sun-cracked, and bear rain imprints.

Economic Products: Oil and Gas

In the Upper Devonian of western Pennsylvania, West Virginia, Ohio, and New York, vast quantities of petroleum and natural

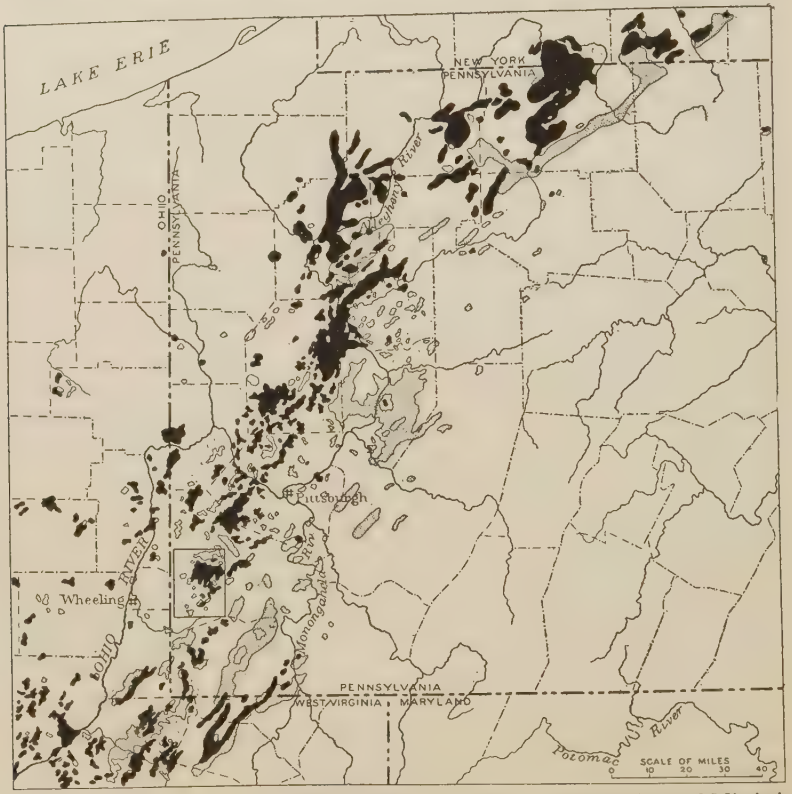


Fig. 421. — Sketch map of underground oil and gas "pools" in Devonian and Mississippian strata of Pennsylvania and adjoining states. Black areas, oil pools; dotted areas, gas. After M. J. Munn, U. S. Geol. Surv.

gas have been obtained by drilling. This was the first exploited field in America, beginning in 1859 with 2000 barrels. During the next forty-five years about 90,000 wells were driven at a cost of about $360,000,000, the yield in that interval being more than 750,000,000 barrels. The field is still productive, more than

twenty distinct horizons yielding petroleum (Oliphant). The map, Fig. 421, shows the areal extent of the underground pools. The oil and gas are stored in coarse, open-textured sandstones and conglomerates, and because of this the term *oil-sand* has come to be applied by drillers to all horizons yielding these volatile hydrocarbons. The number of underground oil-sand layers in a locality varies between one and three, and the productive wells are from 100 to 4000 feet beneath the surface. The oil and gas pools lie parallel to the principal geologic folds of the region (see also pages 637–641).

"Although petroleum as an earth product has been known for centuries, the modern development of the oil and gas industry as well as knowledge regarding the geologic relations of oil dates only from the completion of the Drake well at Titusville, Pa., August 28, 1859. To one familiar with the equipment of to-day, it is hard to realize the difficulties encountered in drilling this pioneer well and that at least one year was consumed in sinking to a depth of 69 feet. Out of this humble and crude beginning have grown the enormous oil and gas industries of the present time, industries that reach to the farthest corner of the globe and involve hundreds of millions of dollars." (Campbell.)

"Drilling with the object of finding new productive territory is of a most speculative nature. Any one of five results may be the outcome of the well when the sand is pierced. (1) The sand rock may be found to be hard and close, incapable of holding oil or permitting the flow of any liquids through its mass; (2) the sand may be good but perfectly dry; or (3) it may be good sand and be completely saturated with salt water, which may fill the well to a depth of several hundred feet or even in some cases flow out upon the derrick floor. Favorable results may have any degree of success. (4) Gas may be found with hundreds of pounds of rock pressure to the square inch and in a volume of millions of feet a day, or there may be only sufficient gas to serve a house or one or two boilers. (5) Oil may be encountered in such quantities and with such pressure that it will gush from the well at the rate of thousands of barrels a day, or there may be only a gradual seeping of oil into the well that will amount to but a barrel or two a day." (Griswold and Munn, 1907.)

CHAPTER XXXIX

THE OLD RED AND THE PROPHECY OF VERTEBRATE DOMINANCE

There is no more significant or picturesque period in the history of the earth than the Devonian. This is the time when the former nakedness of the lands becomes clothed with a deeper verdure and the first forests appear, providing the needed homes and food for the invasion of the continents by the ever-hungry descendants of the denizens of the sea. The conquest is first attained by the invertebrates — the scorpions, shell-fish, worms, and insects. Of greater significance, however, is the adaptation of other marine animals to the land, which eventually leads to the origin of the fishes, the advance guard of the vertebrate hosts, through the development of lungs and the increase in mentality.

The invasion of the land is fairly under way in the Devonian, chiefly in the rivers and lakes, but due to the prevailingly arid climates a fierce struggle is instituted among the inhabitants of the then temporary waters, resulting in the dominancy of the better equipped air-breathing fishes, an issue prophetic of vertebrate ascendancy, hereafter never to be questioned in its onward sweep to its culmination in man.

In the previous chapters we have traced the physical conditions and the perfecting of organic evolution in the *seas* up to the close of Devonian time. In this chapter we must deal with the nature of the Devonian *lands*, their climate, and the character of their life. First we shall trace the rise of the land vegetation and forests, and then take up a further study of the Devonian fresh-water fishes described in the two previous chapters. How, where, and why lungs were developed we shall see by following their history from the gilled and worm-like invertebrates of the sea through the half-vertebrates into the fishes with both gills and lungs, the double breathers, as typified by the lung-fishes of the Devonian.

Continental Deposits

Oldest Fossiliferous Strata. — On page 258 the physical characters of continental deposits and their origin are stated, and now we come to the study of the organic record of such deposits. The

oldest of these strata with fossils are of Devonian time. There are, it is true, undoubted continental deposits as early as the Proterozoic, but they are devoid of fossils. From the Devonian period onward, the geologic record often bears testimony to the continental origin of certain deposits and their entombed life, and while such are preserved and accessible more and more as one goes upward in the geologic scale, still the record of the land-living and air-breathing plants and animals is far more imperfect than the record of marine life. This is due to the fact that the organisms of the land are rarely entombed in the sands and muds of the land waters, but are either eaten by their living contemporaries, or oxidized and blown away by the atmosphere. The life of the fresh waters is more apt to be preserved, along with such land-dwelling organisms as may be accidentally drowned or blown into them (leaves), or washed by the floods into the areas of standing waters where burial may take place. Even though burial occurs on land, however, the circulation of ground waters is far more marked in loose continental deposits than in the more completely cemented marine strata, and in this way nearly all the remains have been leached away.

Old Red of Scotland. — The Old Red deposits of Britain are a tremendously thick series of coarse detritals and volcanic effusives, seemingly accumulated in valleys between high mountains that were upheaved during the Caledonian Disturbance. Jukes-Browne states that there were probably five parallel ranges. The maximum thickness of these deposits may be as great as 37,000 feet, but in no single area is there more than 20,000 feet. Nowhere is there a transition, as has so often been stated, from the Silurian into the Old Red, for the contact is an unconformable one, and the break at the top with the Carboniferous is equally distinct. As long ago as 1856 Godwin-Austen regarded these deposits as of fresh-water origin, a conclusion now agreed to by nearly all geologists. They are probably wholly continental, and were accumulated in several independent and subsiding valleys, under a climate more or less arid (see Fig. 422). The record is a very long one and covers most of the Devonian, though sedimentation was interrupted for a considerable time during the Middle Devonian, and because of this stratigraphic break the Old Red is usually divided into a lower and an upper series. We shall here, however, not follow this two-fold division, but use instead the tripartite arrangement of Goodchild, who has devoted many years to a study of the fossils and rocks in the field.

The *Upper Old Red* has a thickness of 1000 feet in places, and is characterized by the presence of the fish *Holoptychius* (Pl. 13, Fig. 4). The series rests with a marked erosional unconformity upon the very uneven surface of the Lower Old Red and more extensively upon the older upturned and metamorphosed Paleozoic. The rocks are red sandstones, deep red clays and marls, conglomerates and breccias, the sandstones passing into yellow or even into white colors (Geikie). The

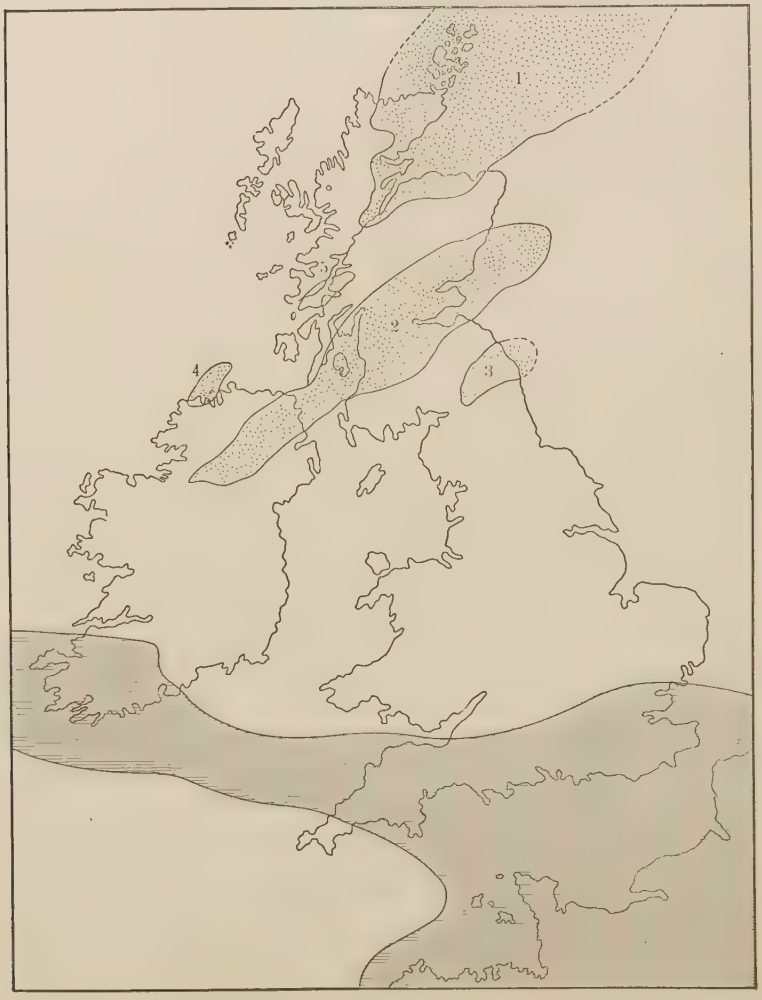


Fig. 422. — Paleogeography of Great Britain in Lower Devonian time, showing the probable relation of the sea (horizontal ruling) to the land (white), and the Old Red lakes of Scotland and Ireland. Modified from Jukes-Browne. 1, Lake Orcadie; 2, Lake Caledonia, 240 × 80 miles; 3, Lake Cheviot; 4, Lake Fanad; 5, Lake Lorne.

series as a whole is remarkably barren of organic remains, but locally there are many fishes thought to have been derived from the upland rivers. The more characteristic of these are the fringe-finned ganoids *Holoptychius* and *Scaumenacia* (Pl. 13, Fig. 3), and the ostracoderms *Asterolepis* and *Bothriolepis*.

The *Middle Old Red* or *Orcadian series* has a thickness of at least 16,000 feet. The series is characterized by the fishes *Dipterus valenciennesi* (Pl. 14, Fig. 5) and *Osteolepis macrolepidotus* (Pl. 13, Fig. 2), and the phyllopod crustacean *Estheria membranacea*. These deposits are best seen on the northern side of the highlands in " Lake Orcadie " in northeastern Scotland, and in Orkney and Shetland. The various separated areas of Old Red deposits, which have been called lakes by Geikie, are distinct " basins of deposits " as described on page 260. Lake Orcadie may have extended as an estuary northeast to Christiania in southern Norway, and possibly even to Petrograd in Russia (Fig. 422).

The dominant color of this middle series is not red, but in Caithness and Thurso in Scotland, where it is well exposed, the deposits consist chiefly of evenly bedded, rippled and sun-cracked, rain-marked, dark gray, bituminous (even impure oil-shales) and calcareous flagstones. These are composed of about 70 per cent of silica, 10 per cent of oxide of iron and alumina, and from 10 to 20 per cent of carbonate of lime. The lower beds of this series, which may be of the age of the Caledonian, are of red sandstones and conglomerates. There are other red sandstones interbedded in the higher parts of the formation. (Geikie.)

Near the middle of the Orcadian series in the Thurso beds occur many fishes, and in the older beds of Achanarras, Stromness and Cromarty as well. About sixty species are known, of which the following genera are most diagnostic: the fringe-finned ganoid *Osteolepis*, the lung-fish *Dipterus valenciennesi*, the armored lung-fish *Coccosteus*, and the ostracoderm *Pterichthys* (Fig. 408).

In Caithness also are found the following land plants: the herbaceous lycopods *Psilophyton* and *Lycopodites milleri*, the small lycopod tree *Lepidodendron nothum*, the tree-fern *Caulopteris peachii*, and the Equisetale or scouring rush *Pinnularia*.

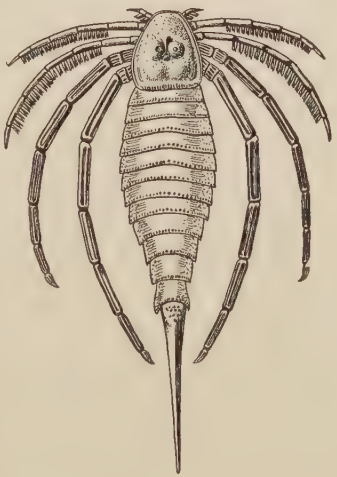


Fig. 423. — The large spike-tailed eurypterid (*Stylonurus excelsior*). $\times \frac{1}{24}$. After Clarke and Ruedemann.

The *Lower Old Red* or *Caledonian series* has a thickness ranging up to 20,000 feet, with the base and top not seen. The characterizing fishes are the ostracoderms *Cephalaspis* and *Pteraspis* (Fig. 407). This series is best developed in the area to the south of the Scottish highlands in " Lake Caledonia " of Geikie. It is preëminently the Old Red of Scotland and occupies the country known to the Romans as Caledonia. Goodchild states that the whole of this vast formation was accumulated under continental conditions, partly in large inland lakes, partly as torrential deposits of various kinds, partly as old desert sands, and partly as the result of extensive volcanic action.

The highest subdivision consists of unfossiliferous, reddish brown or chocolate-colored conglomerates, gray and yellow sandstones, red shales, and gray flags

with occasional bands of limestone, the whole forming the lowland tract of Strathmore. These youngest deposits may yet be shown to be equivalent in age to the lowest beds of the Orcadian series. The middle subdivision consists chiefly of volcanic rocks, mostly andesitic lavas with some tuffs, interbedded with sedimentary strata, attaining a thickness of more than 6000 feet. The lowest division, which has much the appearance of Silurian rocks, consists of graywackes, flagstones, and mudstones.

Near the top of the middle division, but away from the regions of volcanic rocks, have been found myriapods, the lycopod *Psilophyton*, and about twenty species of fishes. The more diagnostic of these are the ostracoderms *Cephalaspis lyelli* (Fig. 407) and *Pteraspis mitchelli;* the acanthodian sharks *Mesacanthus mitchelli*, *Diplacanthus gracilis*, and *Climatius* (Pl. 14, Fig. 1); and the armored shark *Thelodus*, which holds over from the Silurian. At Arbroath are also found an abundance of eurypterids, the best known of which are *Pterygotus anglicus* and *Stylonurus ensiformis* (like Fig. 423).

Old Red in America. — In America there are no fresh-water deposits of Devonian time that were accumulated in inland mountainous areas, like those of Scotland. They are, rather, delta deposits formed by large rivers flowing into the sea, apparently under a semiarid climate. Two of the non-marine animals are shown in Figs. 423 and 425. Clarke regards certain of the Upper Devonian deposits of New York (Oneonta and Catskill) and the sandstones of Gaspé in lower Quebec as of a great coastal lagoon receiving terrigenous sediment rapidly and in vast quantity from the highly elevated old land. In places there are thin, interbedded, marine zones that represent the overwash in times of stress of the outside water bringing in the marine organisms as we find them — sea shells from the littoral. It is in these regions that are found the American Old Red fishes, most of which appear to have come from the rivers and not from the sea. The deposits of Scaumenac, Quebec, which are evenly bedded, gray to greenish, sandy shales, appear to be wholly of fresh-water delta origin, the only fossils being land plants and fishes, in harmony with those of the Upper Devonian of Scotland. There occur eleven species of fishes (selachians three, ostracoderms three, arthrodires one, dipnoans one, ganoids three). No marine fossil of any kind has ever been seen. Not far away, at Campbellton, New Brunswick, however, the deposits are of Lower Devonian age and laid down under the influence of the sea, for here occurs a brecciated limestone holding apparently marine organisms, such as ostracods, fragments of a large *Pterygotus*, *Spirorbis*, and pelagic gastropods (*Cyclora*). Associated in the same formation occur five genera of land plants and nine of fishes (ostracoderms two, arthrodires one, selachians six).

Proof that the Old Red of Scotland is of Continental Origin. — These deposits are often very decidedly cross-bedded, and the

materials are usually poorly assorted. The conglomerates are frequently of great thickness, with erratic bowlders as large as 8 feet in diameter. Ripple-marking is frequent, and the sun-cracking is deep, indicating that there was long exposure to dry air, since the edges of the prisms are often curled. There are also present rain-drop impressions. All of these are characteristic of continental deposits. While the rocks are not red throughout the Old Red series, this is nevertheless the dominant color; it is usually due to the quartz grains being coated and held together by a crust of earthy ferric oxide very much as in the Triassic sandstones of the Connecticut valley, which are deposits of undoubted land origin under a semiarid climate. Further, Goodchild points out that some of the red sandstones of Scotland are often full of desert sand grains, and are highly false-bedded in places, like an old desert sand-dune.

In the Old Red there are no thick, evenly bedded limestones, and the amount of carbonate of lime present at certain horizons is not greater than that found in undoubted continental deposits. The Old Red abounds in land plants and most of the fishes are of unmistakable fresh-water types. Of true marine animals there are none, though the small sharks and the small to gigantic eurypterids may have migrated from such waters. With none of these, however, are associated marine shells, and on the other hand it is well known that a few kinds of sharks are living to-day in fresh waters. If sharks adapt themselves to fresh waters now, why may they not have done so in the past? Therefore, the only evidence against the view that the Old Red is of continental origin is that of the eurypterids.

Eurypterids (Fig. 423) are locally abundant in the lowest beds, one even attaining a length of 6 feet. Previous to the Old Red, all eurypterids occur in unmistakably marine or at least estuarine associations, but toward the close of the Silurian, both in Europe and America, they are nearly always restricted to brackish-water assemblages. After Silurian time none of these animals are found in normal marine associations, and the last occur in the Pennsylvanian, where they again appear either in brackish-water faunas or in association with land plants and with a complete absence of marine animals. It is therefore held, and justifiably so, that the later eurypterids traveled far up the estuaries and even into the fresh-water rivers either in search of food or more probably to spawn.

Mixed Marine and Fresh-water Faunas. — Wherever the Old Red land fishes are found associated with marine faunas, it is seen

that such mixtures have taken place near the shore lines of the Devonian epeiric and shelf seas. Therefore these occurrences may be cases of moribund fresh-water animals floated to the sea by the rivers, or they may be of species that have interchangeable marine and fresh-water habitats, as have many modern fishes, such as the salmon. Kayser, and more especially Walther, holds that the Old Red areas were lagoons of the sea in which the character of the water recurrently changed; for long intervals the sea was present in the lagoons, followed by equally long periods when it was out of them, or the rivers dried out before attaining the sea and then over the areas of the deltas were deposited irregularly variable sheets of desert deposits derived from the highlands.

We are reminded by the Old Red of the Teri region of southern India, where the wide coastal plain is covered by wandering dunes of carmine red sands nearly two hundred feet high, between which are beautiful dark blue lakes whose shores are decorated with palms. Here are forming thick red sandstones with typical dune-bedding, beside thin-banded red clays at the bottoms of the lakes. Not far away are being deposited marine limestones and sandstones decidedly rich in beautiful pearl shells and snails, which gradually pass into coral reefs with their teeming life. Just as these sands of Teri are coated with a thin layer of iron oxide, so were those of the Old Red, and we cannot escape the conviction that both were caused by identical semiarid climatic conditions. (Walther.)

Plants and the Climate. — In the Devonian there is much evidence of land plants, but it is not until the Middle Devonian that we can speak of floras, for in the Lower Devonian these fossils are still very scarce. Although this is not the proper place to discuss the origin of the land plants, which will be taken up in Chapter XLII, it may be said here that paleobotanists hold that the Devonian or oldest floras probably originated in the marsh areas of the rivers and tidal flats along the seashores, and that they seemingly extracted much of their carbon dioxide from the water through their roots and in least degree from the air. At first there was little woody structure in them and therefore the plants were delicate and small, with thin, slender, or spiny leaves. Their evolution, however, was rapid, for in the Upper Devonian there was a considerably diversified flora, forming the oldest or first forest, in which flourished fern-like plants, rushes, tall ground pines (lycopods), and primitive evergreens with woody trunks nearly 2 feet in diameter. Drifted logs of these trees are often found in the marine deposits of Upper Devonian time. As the dominant plants were fern-like forms, this flora of the Upper Devonian has been called, after one of them, the Archæopteris flora, and the time, the *Age of Archæop-*

teris (see Fig. 424). As the flora in its broader aspect was not very unlike that of Pennsylvanian time, the detailed description of it is deferred to Chapter XLII. The Devonian forests, however, were devoid of all insects. One of the most remarkable facts in connection with this flora was its wide distribution and uniform character throughout eastern North America and into the Arctic region, Spitzbergen, and northwestern Europe, indicating equable climates and the complete union of North America and Europe across Greenland, Spitzbergen, Norway, and Great Britain. It is also probable that this region was the place where the first forests had their origin. None of the trees show annual rings of growth attesting to seasonal changes due to a varying climate or to prolonged drought and it is therefore held that the general climate of this time was uniformly warm though arid, the known forests being localized in wet places along the valleys and in the swamp areas. That the climate was warm is further shown in the wide distribution of the reef corals of the seas, which extended even into Arctic regions, but that the air was more or less arid is proved by the prevalence of the oxidized and red continental deposits of Eria.

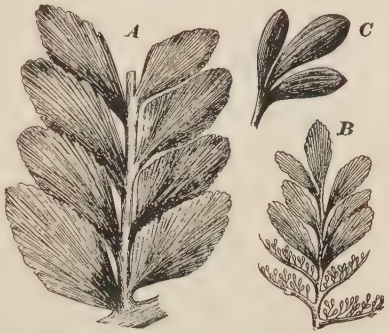


Fig. 424. — Characteristic fern of Devonian time (*Archæopteris hibernica*). *A*, sterile branch, somewhat enlarged to show venation of leaves. *B*, fertile branch, about nat. size. *C*, spore cases, much enlarged. After Schimper and Schenk.

It is probable that the great Middle Devonian submergence of the continents described on page 701 had much to do with the development and spreading of this flora through the production of moist local climates. In other words, insular climates were locally developed in the otherwise general arid condition.

Thin coal beds of very local distribution are occasionally observed in the Old Red continental deposits, but these, as a rule, are of no commercial value; to the scientist, however, they indicate that swampy areas abounding in plants occurred where the coals are found. On Bear Island, to the north of Norway, are found beds of good bituminous coal sometimes 3.5 feet in depth.

Origin of Devonian Fishes

A general description of fishes is given in Chapter XXXVII, along with a detailed account of the various kinds found in the Devonian.

It is probable that the line of fish-like animals arose in some marine invertebrate ancestor, and it is apparently also true that the ancestral half-vertebrates have always lived in the sea as they do to-day, and that they probably were like the worm-like hemichordates described on page 691. It also seems probable that the vertebrate evolution remained in the sea up to at least the lancelet stage, for these animals are wholly marine in habitat. The further early vertebrate steps in evolution are unknown.

Geologic Record. — The oldest known fishes are the ostracoderms found in the Middle Ordovician of Colorado, South Dakota, and Wyoming (like Fig. 407). If the students of fossil fishes are correct in their conclusion that these animals had shark ancestors, then we are forced to add that the latter had their origin still earlier, and possibly as early as the oldest Cambrian. The geologic record shows clearly that the higher or more recent sharks have always been essentially marine animals, but that a few of them have adapted themselves to fresh waters is well known. However, the Old Red has many small sharks of undoubted fresh-water habitat, and their presence here takes on added significance when we remember that the Ordovician ostracoderms are also thought to have been fresh-water animals. It would seem, therefore, that the ancestors of the small ancient sharks lived in the sea and invaded the fresh waters, where they evolved into the spinous sharks; unfortunately, however, there are as yet no connecting fossils to bear out these surmises.

The spinous sharks were by no means the dominant fishes of the Old Red, nor were the ostracoderms. The majority of the fishes of that time were lung-fishes and ganoids, animals that were then more or less well adapted to double breathing, that is, had not only functional gills as have all fishes, but, in addition, lungs. We therefore see, further, that there must have been fresh-water fishes in the Ordovician and that they had evolved into the lung-fishes of the Silurian and Devonian. In other words, it appears to be a safe inference that the fresh-water fishes of the Devonian consisted of spinous sharks, ostracoderms, lung-fishes, and ganoids. Hence, the most fundamental evolution among the fishes had taken place previous to the Devonian, and the vista in the Ordovician shows that the greater part of it had occurred before the middle of that period.

Ancestors of Fishes. — Representatives of all of the probable vertebrate ancestors, whether invertebrates, half-vertebrates, or primitive vertebrates, up to the lancelet stage, are now living in the sea. To this may be added the further fact that all of these possible ancestral stocks are inhabitants of the shallow seas, and that the lancelets live just off the shores of the warmer waters.

As the marine lancelets represent more nearly than any other living type the probable progenitors of the higher vertebrates (Fig. 412), it seems safe to assume that the subsequent evolution up to the direct ancestors of the spinous sharks also took place in the shallow-water seas, for we find their spines in marine strata of the early Silurian. When the seas spread over the land, the primitive fishes occupied their widened habitat, and when the continents emerged, some of them were probably retained in the relic seas. In this connection, it should be remembered that there were three submergences of North America during the Paleozoic and previous to the appearance of the ostracoderms in the Middle Ordovician. Thus caught in the relic seas, the environment of the ancestors of the spinous sharks was bound to be gradually changed into one of fresh water, and even to dry land under the arid climates prevalent at that time. There was thus set up a struggle for existence which must have been fierce, bringing on stimuli which it is thought eventually resulted in the production of air-breathing animals. This latter aspect is discussed further on in the chapter.*

Food of Devonian Fresh-water Fishes. — Among living fishes some feed exclusively on plants, some on plants and animals alike, some exclusively on animals, and others on the mud in which minute plants and animals occur. The majority of fishes, however, feed on other fishes, without much regard to species, devouring their own young as readily as those of any other kind. Teeth with blunt tips usually serve for crushing shells; teeth with serrated edges often signify plant-feeding forms; while strong incisors may indicate the choice of snails and crabs as food. In general, the sharper the teeth and the larger the mouth, the more distinctly a species is a fish-eater. Small-mouthed fishes are apt to be plant- or mud-eaters. Fishes grow as long as they live and their size depends upon their ancestry plus the amount of food procurable: the length of life is variable; some exist many years, others are short-lived, and some appear to be annuals. (Jordan.)

* A very instructive paper on this subject, by Professor Chamberlin, is entitled "On the habitat of the early vertebrates" (Jour. Geol., Vol. 8, 1900, pp. 400–412).

From the living lung-fishes we learn that certain forms (*Lepidosiren*) inhabit muddy streams and marshes, where they feed on plants. Others feed on worms, insects, shellfish, crustaceans, and frogs. The lung-fishes eat voraciously during the rainy season, storing up great quantities of fat between the muscles. During the dry season they cease to feed and are sustained by this body fat until the water returns.

In the fresh-water deposits of Devonian time there is not as yet known a single definitely determined water-living plant, nor invertebrates of any kind other than bivalves (see Fig. 425) and myriapods. The ultimate basis of fish food, however, must have been water plants and algæ. There was probably also an abundance of earthworms present though their bodies were too soft for preservation as fossils. The sluggish bottom-living Devonian fishes were, then, dependent upon water plants, and upon these fishes subsisted the more active carnivorous forms. That food was still scarce in the streams and lakes of Devonian time is attested by the average small size of these ancient fishes, few of which exceeded 6 inches in length. In the marine waters where food was plentiful, the average length of fishes was far greater, and one at least of the Arthrodira attained to 20 feet. It is probably because of the abundance of food in the seas and oceans that we see so many different stocks of land fishes returning and adapting themselves to these more favorable habitats.

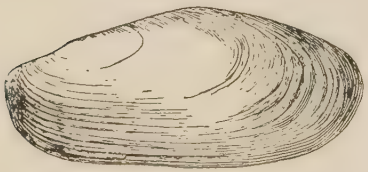


Fig. 425. — Probable fresh-water Devonian bivalve (*Amnigenia catskillensis*), from New York. × ½. After Hall.

Origin of Double Breathing in Fishes

Breathing Organs of Marine Animals. — A survey of typical marine animals reveals many and diverse methods for the extraction of the free oxygen from the water, but whatever the kind of breathing organ, it is always of the same fundamental type, a localized organ or organs having delicate canals with very thin membranes in which the blood circulates, bringing the red corpuscles into almost direct contact with the surrounding water. These red corpuscles have decided affinity for oxygen, which they extract from the water and carry through the circulation of the blood to all parts of the animal's body. Nowhere in the sea has any animal an additional organ for the extraction of oxygen directly

from the air, excepting in such stocks as are known to have had land-living ancestors.

Evolution of Lungs. — There is in all fishes above the sharks a structure known as the air or swimming bladder, which is structurally a sac-like outgrowth, single or paired, of the alimentary canal. Two exceptions to this rule are found, first, in those fishes which, because they inhabit swiftly running waters, have developed quick darting movements and have therefore lost the air bladder; and, second, in the flounders that lie upon the sea bottom awaiting their prey.

The principal function of this structure in living fishes is that of a hydrostatic organ, to give buoyancy to the animals, and it is controlled by muscles in such a way as to permit its possessor to remain at any desired level in the water. The air bladder is the homologue of the lungs of the terrestrial vertebrates, and is utilized by the so-called lung-fishes, and to a limited extent by other relic fishes (*Amia*, *Lepidosteus*, *Polypterus*) as a respiratory organ supplementary to the gills.

The great range of modification of this structure shows it to be of extremely ancient origin, and its incipient condition is probably shown by a pair of pouch-like outgrowths of the pharynx, or throat cavity, in the sharks. Stagnation of the water and a loss of free oxygen would bring the fishes to the surface to gulp down air, like goldfishes in a neglected aquarium, and such pouches, if supplied with blood-vessels, would serve in a very rudimentary way to aid in aërating the blood. A premium placed upon such structures would stimulate their development to the condition seen in the modern lung-fishes. Almost simultaneously the secondary function of buoyancy would be acquired, and in those fishes in which the power to breathe the atmosphere was unnecessary, this would become the main purpose of the organ. In many teleosts, or modern bony fishes, the connection between the air bladder and throat has been lost, and with it the possibility of respiratory use. On the other hand, permanent adaptation to land life among vertebrates could only come about through the perfection of the breathing function on the part of this ancient structure. (Lull.)

Origin of Lungs in Animals Living in Temporary Bodies of Water. — Animals originating and living in permanent bodies of water, and especially in the ocean, have no need to breathe the air, and it is, therefore, held that the stimulus for such an alteration could have taken place only where the water periodically failed the animals. Such places are very few, practically only the strand areas and the fresh waters of the land under a more or less arid climate.

Along the strand-line the breathing of air has been developed but seldom, apparently only by a few groups of gastropods, crustaceans (land crabs), insects, and scorpions. No fish permanently breathing air is known to inhabit the region between low and high tides, though several kinds live here for a time in search of food. In all of these cases there are developed in the gills secondary spongy structures that absorb, while moist, the oxygen of the atmosphere. However, these secondary gill structures do not correspond to the homologues of the lungs. On the other hand, in none of the marine deltas of the present does one find the climatic conditions necessary to force fishes to develop into lung-fishes, nor do they occur in the areas of the strand-lines or in the courses of the permanent rivers. Nowhere is there in these places a transition zone forcing the water-living fishes to adapt themselves to the dry land.

It is well known that large bodies of sea water have been captured from the ocean (for example, Caspian, Baikal, Nicaragua), and this probably often occurred during the Paleozoic emergences. Just as we have arid regions to-day, so it appears that similar land climates existed during much of Paleozoic time. Under such climates, bodies of water come and go according to the season of rain and drought, and hence various methods are resorted to by the animals to maintain their kind or themselves over the period of drought. During the arid season the struggle for existence is severe, not only because of the abnormal crowding of the individuals into constantly diminishing spaces and the reduction in the amount of available food, but even more so because of the increasingly saline and bitter character of the water. It is thought that under the stimulus of these violent changes the gill-breathing fishes first adapted themselves to burrowing in the sand. Thus protected in water and mud holes there was for a time moisture to pass over the gills, but under such environments life was very precarious and in the struggle most of the individuals were destroyed. After innumerable failures in their efforts to gulp the air into the pharynx, efforts lasting through long geologic time, the lung-fishes were gradually developed and perfected, their first appearance being in late Silurian time.

Homes of Living Lung-fishes. — The conditions pictured here are not fanciful, but are based on the actual habitats of modern Dipnoi, animals that not only maintain life in the foulest of waters, but in times of drought burrow and even encase themselves in a mud cocoon with an air opening at the top, breathe through the mouth after closing the gills, and thus live for months at a time out of water until the drought is over and the rivers return. In Africa the natives often dig such lung-fishes out of the mud for food.

Highest Mentality among Land-living Vertebrates. — Air breathing, once established among the fishes, has resulted in the land vertebrates attaining to the highest mechanical and mental perfection, an evolution necessitated by adaptation to a wide range of environmental conditions as compared with the relative uniformity of the sea. The greatest mentality in the sea has been repeatedly derived from the continents, in that many stocks of land vertebrates have adapted themselves to the sea because of the ease with which they can there prey upon the less alert and intelligent. Such adapted stocks in the course of geologic time grow larger and larger, as, for instance, the whales of to-day, whose origin goes back to the Eocene. Out of such stocks, however, comes no higher mentality. They represent an adaptation in the wrong direction, that is, to an easier life, for the highest mentality has been developed only on the land where the struggle for existence is greatest because of the constant necessity of adaptation to changing environment. Organic supremacy is attained only through constant vigilance.

CHAPTER XL

CARBONIFEROUS OF OLDER GEOLOGISTS, AND THE MISSISSIPPIAN PERIOD

History of the Term Carboniferous. — The geologists of more than a century ago classified the periods of geologic time on the basis of kinds of deposits, as, for example, the Old Red sandstone, the New Red sandstone, the oolitic rocks of Oolite time (Jurassic), the chalk of the Cretaceous, and the coals of the Carboniferous. Such a classification, based on the kinds of rocks, they believed was a natural one, and they also thought that the same kind of materials was deposited everywhere at the same time. This petrologic classification, however, because of its unreliability, has long since been abandoned for the more dependable one based on the contained fossils.

In western Europe, where Geology had its inception, the coal-bearing strata are of wide occurrence, and as long ago as 1808 Omalius used the term "bituminous terraine" for the coal deposits of Belgium. Later the English geologist Conybeare (1821) called these formations the *Carboniferous System* and this term came to be applied to all the strata above the Old Red and beneath the New Red, or Triassic. The term Carboniferous system is still widely used in Europe and embraces the lower series, the Carboniferous or Mountain Limestone, and the upper coal-bearing series, the Coal Measures (William Smith, 1817). The lower limestone series, while of wide distribution, was shown by Murchison and Sedgwick (about 1836) not to be of this rock everywhere, but even in England to be locally replaced by sandy shales that are known as Culm Measures. (The word "Culm" originated in South Wales and refers to a natural slack from anthracitic coal, the origin of this slack being due to the crushing of the coal beds during the process of mountain making. Arber.) This latter term they applied to the lower series when composed of sandy mudstones, and even to-day throughout western Europe Culm (or Kulm) is much in use. Culm Measures and Mountain Limestone are, therefore, regarded as deposits of one time, but laid down under different physical conditions.

Marked Variability of Carboniferous Formations. — The Carboniferous deposits of western Europe are very variable in character, and the time of their deposition is also different in the various areas, indicating that these small basins of deposits were bordered by lands with differing physiography and character of rocks. In addition, there was a deforming movement taking place, for east of the Rhine valley the Coal Measures rest unconformably upon the Culm series. In eastern Europe and Russia the basins of deposits were far larger in areal extent. Under these varying conditions it is to be expected that the thickness of the deposits would also be variable, and in places it attains to 13,000 feet and more.

Divisions of the European Carboniferous. — The European Carboniferous is now separated into two primary divisions, the lower one of which is called *Lower Carboniferous* or Culm (sometimes Dinantian, from the city of Dinant, Belgium), and the upper one, *Coal Measures*. The French geologists further divide the Lower Carboniferous into two series, the lower being their Tournaician (Tournai, Belgium), and the upper their Viséan (Visé, Belgium).

The Coal Measures formation is again divided into two series, the earlier half, or Middle Carboniferous, being widely known as the Westphalian (from the province of Westphalia, Germany) when coal-bearing, and Moscovian (from Moscow) when of normal marine deposits. The upper series, or Upper Carboniferous, is called Stéphanian (St.-Étienne, France) when it has coal deposits, and Uralian (Ural Mountains) when of marine character. Kayser adds a third series, the Namurian (Namur, Belgium), which is referred to the base of the Middle Carboniferous.

The above succession expressed in tabular form is as follows:

Carboniferous	Coal Measures or Upper Carboniferous	Stéphanian or Uralian
		Westphalian or Moscovian
		Namurian
	Lower Carboniferous, Mountain Limestone, Culm, or Dinantian	Viséan
		Tournaician

History of the Term Permian. — In Great Britain occur other higher strata that were at first confused with the Carboniferous, and in Germany certain equivalent red beds were erroneously included in the younger Triassic series. These incorrect references of the beds did not become apparent until after 1841, when Murchison proposed the term *Permian* for a thick series of marine strata that lay above the marine Carboniferous and beneath the continental red Triassic along the western flank of the Ural Mountains in the Government of Perm, Russia. In Germany the equivalent of these deposits was long known as the copper-bearing rocks; in that country the Permian has a lower red, conglomeritic and sandy series of continental origin, known as the *Rotliegende* (lower red), and an

upper shaly and calcareous marine member known as the *Zechstein* (a miners' term, of unknown origin but possibly from *zähe*, meaning *tough*). Because of this two-fold development, the series was called the *Dyas* (meaning two-fold) or Dyassic period, but as this name was of later origin than Murchison's term it could not displace Permian, though it is still used locally. In northern Germany the Permian closes with salt beds upward of 3400 feet thick (see page 674).

Carboniferous of Europe and America compared. — The geologists of Europe now recognize but two systems of rocks above the Devonian and beneath the Triassic, namely, the Carboniferous and Permian systems. It will be shown, however, that their Lower Carboniferous is also clearly distinguishable as an independent system or period. There are, therefore, embraced in the Carboniferous at least three periods, (1) Lower Carboniferous, (2) Upper Carboniferous, and (3) Permian.

In America these three periods are also developed, but the Permian is far less extensive than that of Europe and Asia. On the other hand, the Lower Carboniferous is much better recorded in the Mississippi valley than in any part of Europe, and on the diastrophic principle of classification the rocks are not only clearly separable from the overlying Coal Measures but apparently can be divided into two systems, as will be explained farther on in this chapter. In regard to the Permian of America, its strata are almost everywhere inseparably connected by transition beds with the Coal Measures and therefore both will be described in this book as if they were one period. It is thus apparent that the classification of Carboniferous formations into systems is markedly different in America from that of Europe.

The Productus Seas.— The seas of the three Carboniferous periods the world over were characterized by an abundance and great variety of brachiopods of the genus *Productus* (see Pl. 23), and have hence been called the *Productus seas*. These shells are always common, and as they are of large size, they are the most conspicuous and easily secured fossils of the Carboniferous marine formations. Further, as the genus died out during Permian time, they are the best guide fossils to the Carboniferous strata. It is true that this stock arose in the Middle Devonian, but even though the forms of the ancestral genus *Productella* were not rare in the Upper Devonian, they were then neither large nor common enough to dominate the marine faunas as they did in the Carboniferous throughout the world.

Development of the Carboniferous Succession in America. — Early in the thirties of the past century the term Carboniferous was more or less correctly applied to the coal-bearing strata in America. However, it was then and for a long time afterward also erroneously applied to older black shale deposits and much labor was spent upon such Ordovician strata along the Hudson River and elsewhere in a vain endeavor to find coal in them, the belief prevailing that because these formations were black they must have coal under the ground. The surprise of the prospectors for coal was great when the geologists of the New York survey in 1838-1842 told them that if they were to find coal they must turn about and dig upward, in other words, that coal could not be found in these ancient rocks, but only in much younger strata, none of which now occur in New York State, since they have been eroded away.

We need not go deeply into the history of how the American succession of Carboniferous strata was determined, but will add that the Lower Carboniferous has long been called *Subcarboniferous* (Owen, 1852). A part of these strata in Ohio was also known as the *Waverly sandstone series* (Mather, 1838), but not until 1869 was a geographic name proposed to embrace all of the Lower Carboniferous limestones. This was the *Mississippi Group* of Alexander Winchell, who applied the term to the Lower "Carboniferous Limestones of the United States which are so largely developed in the valley of the Mississippi River." In 1891, Professor H. S. Williams revived this term as the *Mississippian series*, defining it as "that series of rocks, prevailingly calcareous, which occupies the interval between the Devonian system and the Coal Measures, and is typically developed in the states forming the upper part of the valley of the Mississippi River, viz., Missouri, Illinois, and Iowa." This name is now in general use as a period term.

The sequence of all of the Carboniferous formations was first worked out in the Mississippi valley, and not in Pennsylvania, because in that state, although the coal-bearing series (Coal Measures) is so well developed, the Lower Carboniferous strata are almost devoid of fossils. The succession of the Coal Measures, on the other hand, was first determined in Pennsylvania by Henry D. Rogers for the United States Government in 1838, and to this sequence Williams in 1891 applied the term *Pennsylvanian series* as a period name, and this is also in general use.

Permian in America. — It has always been difficult to appreciate fully the differences in the marine faunas of the original Permian when compared with those of the Coal Measures of Europe, because

so many of the fossils are very similar or alike. No one now doubts the presence in America of strata equivalent to a part of the Permian of Russia, but as there is in most American areas a complete transition between the Coal Measures and the beds regarded as of Permian age, there is not complete accord among geologists as to where the line between the two systems is to be drawn. Strata of Permian age were first identified by Meek in Kansas in 1857, but there have always been geologists who doubt this correlation. It is not one of easy adjustment because these marine beds gradually go over into red ones that are almost devoid of fossils. Many geologists, on the other hand, avoid the difficulty by calling these beds *Permo-Carboniferous*, a term that truly indicates their position, for they are transitional between the Carboniferous and the Permian. In this book they will be classified, however, as of Permian time, but the formations will be combined with those of the Coal Measures as if representing but a single period, for the reason that there is no break of marked importance in the sedimentation between these two periods in America. In other words, there was but a single sea transgression, for the flooding of the continent continued throughout Pennsylvanian and into early Permian time. Then the seas began to vanish and the North American continent emerged, in the throes of the Appalachian Revolution. This matter will be treated of in more detail later on.

The divisions of the Carboniferous of North America are as follows:

Permo-Pennsylvanian periods

Permian	In Texas	Capitan of Trans-Pecos Texas			
		Double Mountain			
		Clear Fork			
		Wichita, Wreford of Kansas	In Pennsylvania	Dunkard	Autunian and Cuseler
Pennsylvanian	In central	Cisco, Neosho of Kansas		Monongahela	Stéphanian or Uralian
		Canyon		Conemaugh	
		Strawn		Allegheny	Westphalian or Moscovian
		Millsap		Pottsville	
		Bend			

Break

Mississippian period

Tennesseian	Kaskaskia		Chester (Mauch Chunk)
	Ste. Genevieve		
	St. Louis		Meramec
	Spergen		
	Warsaw		

Break

Waverlian	Keokuk	Osage	Madison of the western or Cordilleran sea
	Burlington		
	Fern Glen		
	Kinderhook-Pocono		
	Chattanooga		

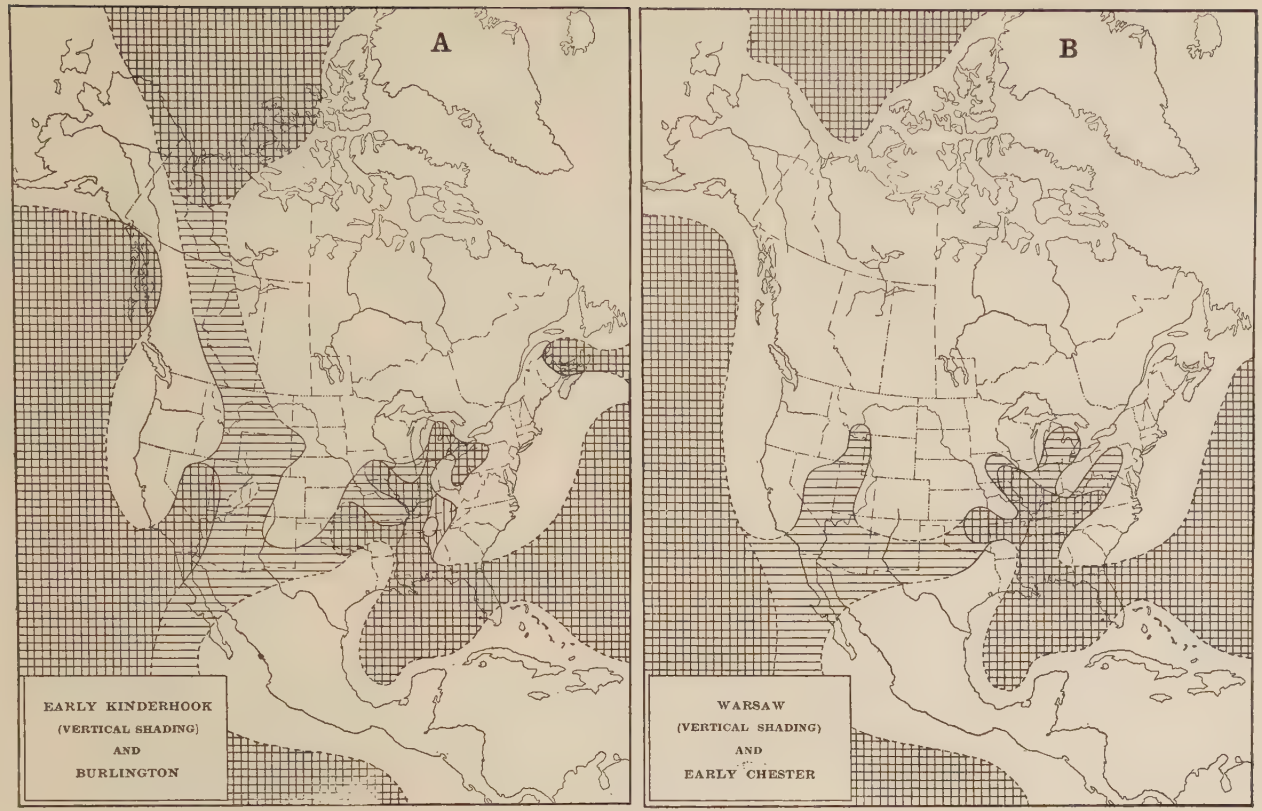


Plate 19. — Mississippian paleogeography.

Mississippian Period

The geologic record of Mississippian time in North America is markedly different from that of the Pennsylvanian, for the former is one of the sea alone, while in the latter in the eastern half of the continent there is an alternation of the sediments of marine floodings with accumulations of coal beds in vast more or less fresh-water swamps. In other words, the Mississippian is a recurrence of Devonian conditions, while the Pennsylvanian formations alternate between those of the sea and land.

Waverlian Seas. — The Devonian period closed with marked retreat of the seas in North America and it appears that all parts of the continent were emergent. How long this complete emergence lasted is not known. The submergence of Waverlian time began first in the Gulf States and along the western side of the Cincinnati uplift, the water depositing nearly everywhere a fine black mud almost devoid of fossils (Chattanooga formation). At this early stage of the inundation the seas were small in extent but in Middle Kinderhook time the waterways were greatly expanded. The most striking change of this time, however, was the reappearance of the *Cordilleran sea,* depositing far and wide throughout the Rocky Mountains a great mass of limestones, known as the Madison limestone, that in places attains to a thickness of 1600 feet. It is exceedingly massive and where upturned the streams have cut in many places deep and picturesque canyons through it. This Cordilleran sea is known as far north as Alberta (Lower Banff shale and limestone with a thickness of 2300 feet) and it is probable that it extended into the Arctic Ocean. That it connected with the Central Interior sea is proved by identical species in both; in fact, more than one third of the Cordilleran forms also occur in the Central Interior sea. The Cordilleran sea, then, remained throughout Waverlian time and seemingly vanished completely at the close of this epoch. During the maximum submergence of Waverlian time about 26 per cent of North America was under the sea (see Pl. 19, Fig. A).

The *northern Appalachian basin* existed throughout Waverlian time east and north of the Cincinnati uplift in the states of Ohio, Michigan, and Pennsylvania, and it is from this area (Waverly, Ohio) that the epoch name is derived. It was a shallow basin with coarse deposits throughout—sandstones and shales, with some conglomerates and but little calcareous material. The life of this basin also had its own impress, but as there were many species common

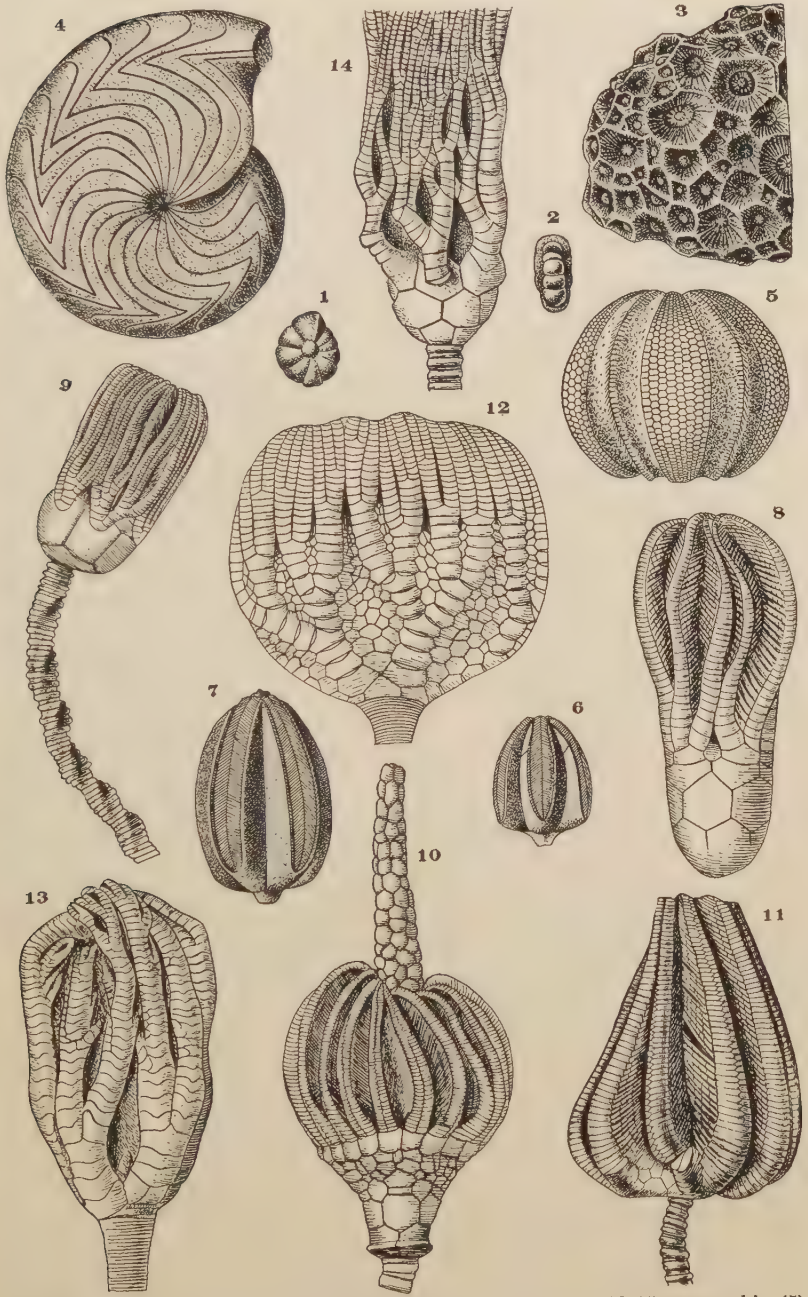


Plate 20. — Mississippian Protozoa (1, 2), reef-coral (3), goniatid (4), sea-urchin (5), blastids (6, 7), and crinids (8–14, 9–11 camerate).
See Appendix B.

to it and the Central Interior sea it is plain that they were connected.

In the *Central Interior sea* the invasion began with black mud deposits (Chattanooga) and for a long time the sediments were of this character, with local sand accumulations. During Kinderhook time the waters west of the Cincinnati uplift clarified and then for a long time remained clear, depositing over great areas the later Kinderhook and Burlington crinidal limestones. The entire thickness of Waverlian deposits at Burlington, Iowa, is about 300 feet, but the series thickens considerably to the south.

In Middle Waverlian times the life was most diversified, and the sea was filled with an abundance of crinids in great variety, a richness of development never again attained by this class of radiate animals (Pl. 20). They were at first delicate forms, becoming larger, thicker plated, coarser, and more ornate with the progress of time. About the city of Burlington alone nearly four hundred species have been found and through the quarrying of the limestones these fine fossils became readily accessible, thus stimulating several collectors living in the city to turn to natural history and geology as a vocation. Other kinds of fossils were also abundant, as, for instance, brachiopods (*Productus*, *Spirifer*), bryozoans, and cup corals, but none attained the profusion of the crinids. That reef-building corals were not present in this warm and clear sea is strange, since reefs were made at this time in Europe. Large sharks were becoming more and more plentiful, for their flat, crushing teeth (cestracionts and cochliodonts, described on page 684) and large fin spines are often abundant, and especially so at the close of this epoch (Keokuk). Among cephalopods, the nautilids were no longer so prevalent as they were in earlier time but they were now more ornate, with spiral ridges and nodes, while the central part of the spiral was more often open. Their descendants, the goniatites (Pl. 20, Fig. 4), were more common than in the Devonian, but this statement applies rather to the European seas than to the Central Interior sea. Trilobites were almost gone. The carnivorous or aggressive life of the Waverlian sea was therefore dominated by the pavement-toothed sharks. It is interesting to note here that the life of this sea was much like that of western Europe, seen to best advantage in the equivalent strata of Belgium (Tournaician), indicating that these waters were in connection with each other.

In the *Acadian area* there was another sea of this time, consisting of narrow connected troughs between mountain ranges made during

the Shickshockian Disturbance (Pl. 19, Fig. A). The wider of these seaways deposited conglomerates, sands, much mud, thin zones of dolomites, and great quantities of gypsum. At the top the series commonly has extensive sheets of igneous rocks. These Acadian deposits are known as the *Windsor series* and at times are rich in fossils. The fauna is a distinct one and has no known relationship to those of other seas, either in America or Europe. The thickness of the rocks is estimated at from 2000 to 5000 feet, and the formations occur in New Brunswick, Nova Scotia, and southwestern Newfoundland. In some troughs occur deposits which seem to be entirely of fresh-water origin, with but few fossils (Horton and Bonaventure formations).

Land Life of Waverlian Time. — Of land life little is known other than plants, and most of these are preserved in the Pocono deposits of gray sandstones and conglomerates, 400 to 1400 feet thick, of the Appalachian trough, which are partly of marine but mainly of fresh-water origin. The plants are so like those of the Pennsylvanian that a description of them is deferred to Chapter XLII. Here we also find the oldest American coal beds, thin accumulations of little commercial value but prophetic of the thicker beds occurring in later formations. However, coal was forming early in Waverlian time in other and widely separated

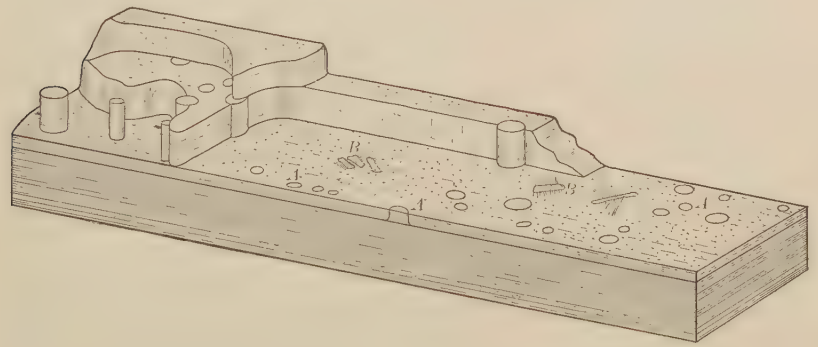


Fig. 426. — Ground plan to scale ($\frac{1}{67}$) to show twenty-seven vertical trees (*Lepidodendron*) in Mississippian strata at Horton Bluff, Nova Scotia. *A*, trunks; *B*, roots. Area sketched 22 × 6 feet. Drawn by W. A. Bell.

places, as in arctic Alaska (Capes Lisburne and Thompson), southern Siberia, and Scotland; and later thin coal beds were accumulating in western Europe in some of the Culm deposits. At Cape Lisburne the coals are non-coking and semi-bituminous, in beds up to 4 feet thick of clean coal, which is now mined.

In the Horton formation of the Evangeline country, Nova Scotia, many land plants are found and here occur also several zones with the bases of small trees (*Lepidodendron*, see page 769) standing vertically, their roots preserved in the ancient soil of the forests. On a surface 120 by 15 feet, Walter A. Bell in 1914 counted ninety-six vertical trunks embedded in a dark greenish, sandy-mud matrix. A part of this layer is illustrated in Fig. 426.

Fresh-water fishes are practically unknown in the American deposits of the Waverlian period, but those of Europe indicate a marked decline of the stocks seen in Devonian time. Of land vertebrates also the record is almost a blank, and the little that is known will be presented at the close of this chapter.

Close of Waverlian Time. — The Waverlian submergence was at its height late in Burlington time and the emergent period continued during Keokuk time. The Central Interior sea again became muddy in the north, where shales and sandy shales dominate, and even the limestones farther south are less pure than those of earlier time. The greatest changes, however, were in the Cordilleran sea, which appears to have been completely withdrawn and did not reappear for a long interval. As the emergence of the continent seems to have been complete, the evidence is in favor of dividing the Mississippian into two periods instead of one. Ulrich was the first to point out this general emergence and to apply to the subsequent submergence the period term *Tennesseian*.

Tennesseian Seas. — Tennesseian time in North America was one of much emergence, for the only marine deposits known to be of this epoch are those of the Central Interior sea and the southern Appalachian and Cordilleran troughs. The whole of the Nashville dome, however, was submerged (see Pl. 19, Fig. B). Nowhere are there more than 1100 to 1800 feet of sediments, most of which in the center of the area are limestones and oolites. On the flanks and especially along southern Appalachia, however, there are sandy or calcareous shales that in the northeast are, in the main, of continental origin, being soft, red, sandy shales devoid of fossils (Mauch Chunk, at Pottsville, Pennsylvania, 3000 feet thick, thinning to 600 feet in western Pennsylvania and 40 feet in West Virginia). During the Tennesseian it appears that at no time was more than 12 per cent of North America submerged, while the average for the epoch may have been about 8 per cent. Finally, all the waters were withdrawn except in the Quachita geosyncline south of Ozarkia, since in Arkansas there appear to be strata that are transitional into the next or Pennsylvanian period.

Life of Tennesseian Time. — The marine life of Tennesseian time differs in many ways from that of the Waverlian, but as it is largely a direct outgrowth of the latter it naturally cannot vary greatly. One of the noticeable features of this life is a dwarf fauna of more than seventy species which reappears at least four times but is always connected with the same physical environment, shallow-water oolite deposits. Abundantly associated with this fauna is a single species of Foraminifera, a division of the Protozoa (Pl. 20, Figs. 1, 2), which will be described in a later chapter. This life assemblage (biota) is known as the Spergen fauna because it is best developed in the Spergen formation of Indiana. The crinids were no longer so diversified as they were in the preceding epoch, but two other groups of echinoderms were far better developed. These were the blastids (*Pentremites*, Pl. 20, Figs. 6, 7) described elsewhere (page 658), which are the guide fossils to the marine deposits of this time, and in places are so common that geologists have called the beds the Pentremital limestone; and, associated with them, though far less common, the equally characteristic sea-urchins known as *Melonechinus* (the melon-like urchin, see Pl. 20, Fig. 5, and page 656). Bryozoa with a thick, screw-like axis (*Archimedes*) were also characteristic of this epoch and certain horizons filled with them have been called the Archimedes limestone. Pavement-toothed sharks like those of the previous epoch were still prevalent but were rapidly dying out and not of marked significance in later times. There were many kinds of cup corals, and one type of compound coral (*Axinura*, see Pl. 20, Fig. 3), which was especially characteristic of this epoch, formed small reefs.

Land Vertebrates. — Toward the close of Tennesseian time throughout the continental deposits of Pennsylvania known as the Mauch Chunk are seen the tracks of many kinds of amphibians, nearly all of which are still undescribed. Lea in 1849 collected a most interesting slab, a little over 5 feet long, with six successive series of foot impressions made by an amphibian (*Palæosauropus*) with a 13-inch stride. This slab is ripple-marked and has rain imprints, indicating a mud flat of land origin, over which the animal walked when the deposit was yet soft and wet. Another amphibian track has been found in Giles County, Virginia (*Dromopus*).

Quachita Disturbance Toward Close of Tennesseian Time. — In the southern Appalachian geosyncline of central Alabama there are more than 3000 feet of continental conglomerates and sandstones of earliest Pennsylvanian age. Farther west in the Quachita (pronounced wash′-e-tah) geosyncline of Arkansas, Oklahoma, and

Texas the marine and brackish-water sediments of the same period exceed 8000 feet, all of which coarse sedimentation indicates that southern Appalachia and Mexico (or the ancient land Columbia) had been in decided elevation during the latter part of Tennesseian time. It is these orogenic movements, followed by the Quachita interval of erosion and the resulting unconformities, that distinguish the Tennesseian from the Pennsylvanian. To emphasize this it is proposed to speak of these movements by the term *Quachita Disturbance*. Similar movements were of even greater extent throughout western Europe.

Petroleum. — Natural oil is obtained in the Mauch Chunk (Keener sand) of southeastern Ohio and West Virginia, and in the Pocono (Big Injun and Squaw sands) of southeastern Pennsylvania, southeastern Ohio, West Virginia, and eastern Kentucky. In this same area there are ten productive oil horizons above the Mauch Chunk and beneath the Pittsburgh coal bed; in other words, all are in Pennsylvanian sediments (four in the Pottsville, three in the Allegheny, and three in the Conemaugh).

Geological Map. — The surface exposures of the Carboniferous formations are shown on the Geological Map of North America at the end of this book.

CHAPTER XLI

PENNSYLVANIAN-PERMIAN PERIODS, THE TIME OF GREATEST COAL MAKING

Important Events in Europe

Two Cycles of Oceanic Spreading.—Nearly everywhere throughout Europe and Asia the Upper Carboniferous and Permian were marked by two cycles of oceanic spreading. While there may have been places where the seas were continuous from the one period into the other, this was not the rule. The stratigraphic succession, however, is very different in the various regions exposing the formations deposited in these seas, this being due to the marked deformation which went on for a very long time throughout Europe. In North America the period of mountain making began later, and, as the oscillatory nature of our Pennsylvanian seas was seemingly connected with the simultaneous deformation going on in Europe, it is well to present here a brief review of these latter movements.

Paleozoic Alps of Europe. — The Carboniferous period was a time of marked crustal movement, and was thus the cause of far-reaching changes in the distribution of land and sea. In central and western Europe, according to Kayser, the movements began shortly after the close of Culm time, continued with decreasing intensity throughout all of the Upper Carboniferous, and were renewed in the Permian. In the heart of Europe there arose a mighty chain of folded mountains, the *Paleozoic Alps of Europe*, whose stumps may be seen in the mature mountains of massive rocks in Germany, France, England, and Ireland to-day (see map, Fig. 427; their general aspect may be seen in Fig. 296). The western ranges extending from Ireland across Wales and southern England to the central plateau of France, Suess has named the *Armorican Mountains;* the eastern ranges extending from southern France across the Vosges and the Black Forest to the Thuringian Forest, the Harz, the Fichtelgebirge, Bohemia, and the Sudeten, and possibly even farther east, he calls the *Variscian Alps*. The folding of the Urals also began in later Carboniferous time and attained its climax in the Permian. Even in Armenia, central and

eastern Asia, and North America can be followed the traces of the mountain-making movements of this time (see Fig. 427).

Intrusives. — Hand in hand with these dislocations arose enormous masses of eruptive rocks, especially granite in stocks and bathyliths, accompanied by porphyries of various kinds. The granitic rocks of the Harz, the Thuringian Forest, the Erzgebirge of Saxony, the Vosges and other regions are of Carboniferous age. Outside of Germany the intrusions of granite (mainly laccolithic) and other eruptive rocks played a large rôle in the Carboniferous; for instance, in Brittany, Cornwall, Scotland, and southern Norway.

Fig. 427. — Stereographic map of the eastern hemisphere, after Penfield, showing the Paleozoic Alps of Europe and many other mountain ranges formed at the close of the Paleozoic. Mainly after Arldt.

Important Events in North America

Submergence in North America. — The geologic history of North America during Pennsylvanian time was one almost devoid of crustal movements other than local warpings and periodic small subsidences of the sea bottoms. It was a period of quiet, for nearly

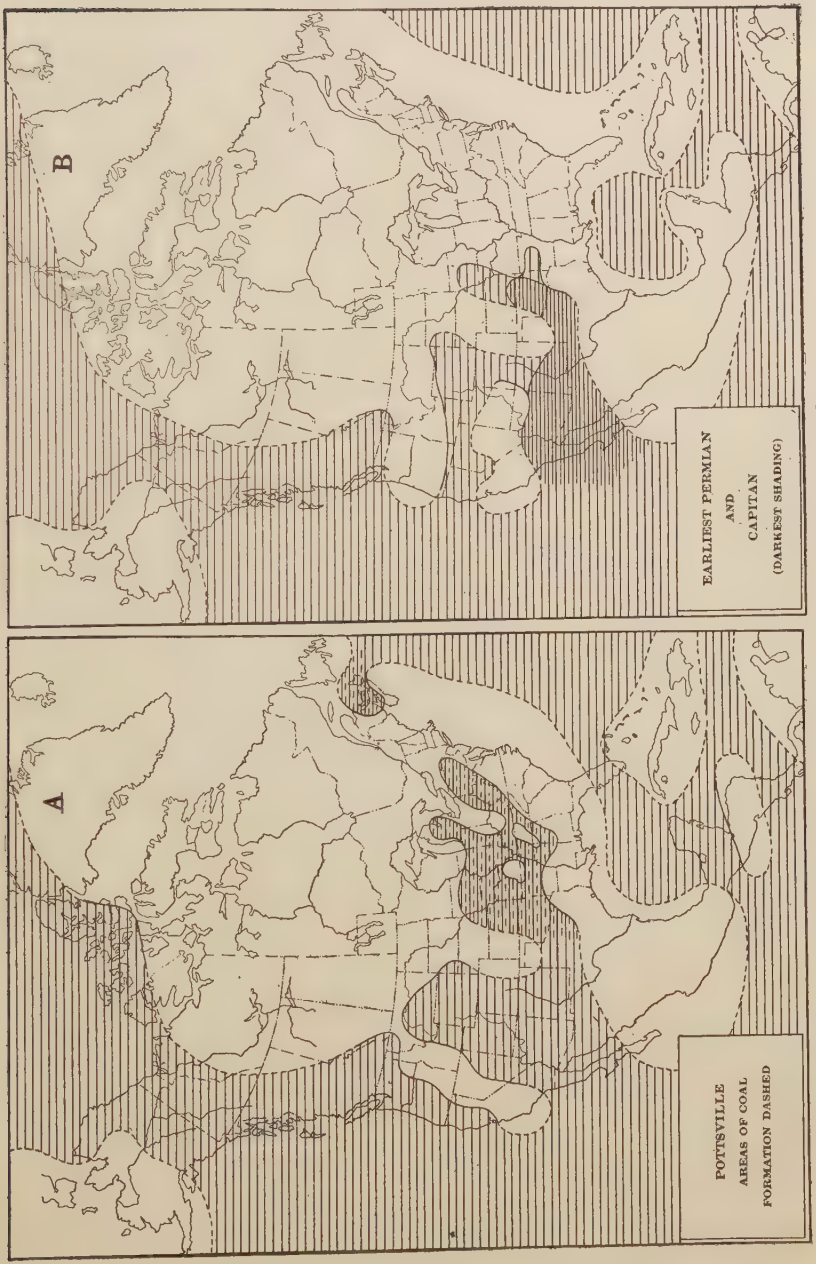


Plate 21. — Pennsylvanian-Permian paleogeography.

everywhere its deposits are distinguished from the older formations only by disconformity (see page 292). The seas quietly submerged the continent, coming mainly from the southwest and overlapping the land northward and eastward. The submergence was greatest in early Pennsylvanian time, when more than 30 per cent of North America was again under the sea. During the latter half of the Pennsylvanian, or possibly even earlier, the sea-level was oscillatory, and a retreat of the flood began late in this period, so that early in Permian time probably less than 5 per cent of the continent remained submerged. The waters continued to retreat rapidly and the sea was finally restricted more and more to the southwest of the United States (see Pl. 21).

While it appears that the greater part of the continent was not undergoing more than crustal warping in Pennsylvanian time, there seems to have been more decided unrest along the entire Pacific area from northern California into arctic Alaska. Here the limestones and calcareous shales of the Pennsylvanian and the early Permian are interbedded with much extrusive igneous material. The thickness in California is not less than 4600 feet, with a maximum of 10,000 feet, while in the Copper River region of Alaska it is nearly 7000 feet. The calcareous deposits often abound in fossils unrelated to those found elsewhere in North America; they are of the Pacific realm, while the life record of the eastern seas accords better with that of northern Europe, though in the main it is best regarded as constituting the North American province. Long after Pennsylvanian time had begun there was also decided crustal movement in western Colorado, Utah, and Arizona, and this is probably to be associated with the deformation of the Pacific border.

Sea of the Rocky Mountains Area. — In a previous paragraph it was stated that the Pennsylvanian seas in the area of the United States came in from the southwest, and as the nature of the sedimentary record of this submergence is very different in the east from that in the west, it must now be described. If we eliminate the Pacific province of indefinite marginal extension, it can be said that the life of these southern waters had throughout a fairly uniform fauna. However, in the area of the Rocky Mountains and the Great Plains, wherever Pennsylvanian formations (not including the Permian of the southern area) are known, they are of normal marine waters, and nowhere, in either Pennsylvanian or Permian strata, is there an alternation of this condition with that of coal making, such as is found in the central and eastern parts of the

country. In other words, in the western part of the United States there are no coal accumulations of this age, and the strata are nearly always limestones with calcareous shales (see Pl. 21).

Great Coal Deposits. — The most striking feature of the Pennsylvanian or Coal Measures in North America, Europe, and China is the fact that they contain the greatest known accumulations of coal. This has long been recognized and it led the older geologists to name the period the Coal Measures. It is true that much coal was laid down subsequently, and especially during the Cretaceous, but at no other time was so much valuable fuel deposited as during the Pennsylvanian. Because the nature of coal and its mode of formation are of such great importance to humanity, a special chapter will be devoted to them, and another one will describe the coal flora; in this chapter we shall present only a general statement of the main events and life characteristics of Coal Measures time.

Central Interior and Appalachian Seas. — In the Appalachian basin east of the Cincinnati uplift, and in the greater Central Interior sea to the west of this axis and extending into Nebraska, Kansas, Oklahoma, and Texas, the formations have more or less alternations of marine deposits with coal accumulations (see Pl. 21). It was in these areas, therefore, that the sea-level was oscillatory, and here the workable coals occur. In the Central Interior basin the coals are associated with more normal marine faunas and are interbedded with calcareous shales and limestones, this generalization applying in the main to the western side of the Cincinnati axis and less to the eastern side. In the Appalachian basin the mass of strata is not only thicker but also coarser, consisting, in general, of sandy shales and sandstones with the marine and calcareous zones inconspicuous or, locally, even absent, the marine zones vanishing eastward. Here also the coal accumulations are thicker, as the swamps were of greater areal extent and less often under the influence of the sea.

Character of Central Interior Deposits. — The essentially calcareous deposits of Pennsylvanian-Permian time in eastern Kansas have a united thickness of about 4600 feet, thinning into Nebraska and Iowa but thickening greatly southward, especially the lowest shale series with coal beds (Cherokee), which attains to 9000 feet in southern Oklahoma. Above lie about 3000 feet of younger Pennsylvanian-Permian deposits. In general, the series is an alternation of shale and sandstone, for the calcareous deposits of Kansas thin southward while the sandstones of Oklahoma vanish north-

ward. Furthermore, the fossiliferous marine condition of these beds in Kansas gradually vanishes more and more toward Oklahoma, and the greater part of the higher series changes into the widely known *red beds* of that state, Texas, and the southern Great Plains country (see Pl. 21, Fig. B). With the appearance of the red deposits not only do the marine fossils disappear, but tremendous amounts of gypsum occur in Oklahoma, which was the center of these sulphate-of-lime waters, and hence is often referred to as the "Gypsum State." On going farther south the amount of gypsum becomes less, the red beds yield very interesting amphibian and reptilian remains, and gradually the sediments change back again

Fig. 428. — Permian sandstone, 700 feet thick, Canyon de Chelly, between Del Muerto and Monument canyons, Arizona. Photograph from W. C. Mendenhall and H. E. Gregory.

in central and more especially in southwestern Texas (Rio Grande region with 8000 feet) to normal marine deposits with an abundance of invertebrate fossils.

From Oklahoma eastward into Arkansas the great thickness mentioned above is maintained, but here the red beds are practically absent. This tremendous amount of mud could not have been derived from small Ozarkia, but must have come from the southwest, or the land that has been called Columbia (see Figs. 428, 429). It is apparent, then, from the above paragraphs that the seas

retreated at first in the north, and that the last of the submergence vanished in the southwestern portion of the United States.

The red color and the presence of gypsum and salt are the striking phenomena of the late Pennsylvanian and Permian deposits of the southwestern United States and Europe. With the retreat of the Pennsylvanian seas and until their return in Europe in the Permian, the brackish- and fresh-water formations are as stated, and these conditions are interpreted as due to dry climates, evaporating the water, precipitating the salts, and oxidizing the sediments. It is also probable that the air was cool rather than warm, for at

Fig. 429. — Permian shales, sandstones, and lava flow (flat bench in center of picture), Little Colorado Canyon below mouth of Moenkopi Canyon, Arizona. Coconino Point in distance. Photograph from H. E. Gregory.

this time were accumulated the many glacial deposits mentioned elsewhere (page 760).

Deposits in Acadia. — In the Maritime Provinces of eastern Canada the Pennsylvanian is well developed and usually of very great thickness. The celebrated Joggins section of Nova Scotia is 13,000 feet in depth and consists entirely of continental deposits. The Cape Breton series is 10,000 feet thick and the Pictou field has a similar thickness. The Riversdale and Harrington beds (with marine zones) and the plant-bearing strata ("fern ledges" of fresh-water origin) near St. John, New Brunswick, are also of Pennsylvanian age. It is very rare for marine fossils to be reported from this region, and the few that have been found indicate

early Pennsylvanian time. On Prince Edward Island the Permo-Carboniferous has an exposed thickness of over 2000 feet and consists of soft reddish shales and sandstones.

Appalachian Revolution. — Earlier in this chapter it was stated that, with the exception of the Pacific border area, the seas began to vanish toward the close of the Pennsylvanian, and that in early Permian time the continent had again nearly all emerged from the sea. Finally, by middle Permian time probably all of the water

Fig. 430. — Stereographic map of the western hemisphere, after Penfield, showing the position of the Appalachian mountain ranges elevated toward the close of the Paleozoic.

of the Pacific submergence had also been withdrawn, and then for a long time there is no record other than that of continental erosion in both regions.

Previous to this time, the continent, during the Paleozoic era, had been deformed in the east at least four times, although none of these disturbances had the significance of a revolution (see page

579). These were the Green Mountains, Taconic, Shickshockian, and Quachita disturbances. Each one, in turn, folded some area of Appalachia, and since the Taconic Disturbance at the end of the Ordovician there had been laid down in the Appalachian trough of Pennsylvania a maximum of 26,390 feet of strata (6490 Silurian, 13,000 Devonian, 4400 Mississippian, and 2500 Pennsylvanian). It was not alone the loss of balance between the area of loading and sinking (Appalachian trough) and those of erosion and unloading (Acadia and Appalachia) that started the revolution, but it was primarily due to the shrinkage of the earth, possibly as the result of cooling, thus causing the earth's circumference to shorten through folding.

During the Appalachian Revolution much of eastern North America was again thrown into pronounced folds, faulted and widely thrust to the west and northwest (see Fig. 430). This deformation was greater than at any other time before or after, and the area of folding reached from Newfoundland to Alabama, and westward to the Allegheny and Cumberland plateaus. The amount of compression in Oklahoma, Arkansas and the southwest, and along the Pacific is not yet known and may have been slight, but volcanoes were active from California to Alaska. Finally the continent was completely emergent, and it was as extensive then as now or as at any time since the close of the Proterozoic. In other words, the Appalachian Revolution was one of the most critical periods in the history of the earth, and may have been the greatest of them all in its results (see Figs. 427 and 430).

How high the Appalachian Mountains stood in late Permian times cannot be stated. On the basis of the folds that have been measured in Pennsylvania, it has been suggested that they may have been 5 miles high. However, we must not forget that these folds are not altogether due to the Appalachian Revolution, but are the result of this grander movement plus at least four earlier disturbances. These mountain ranges certainly must have had peaks 3 miles high.

Life of the Closing Paleozoic Periods

Cosmopolitan Land Floras. — We have seen in earlier chapters that plant combinations or floras are not known earlier than the Middle Devonian. Although their description is deferred to the following chapter, it may be stated here that with the Pennsylvanian, land plants began to be common in America, that the floras were then large and varied, and also that if we do not restrict ourselves too much to details, these floras, and the land animals as well, were not only very much alike in the different lands of the northern hemisphere, but that there was a marked similarity even

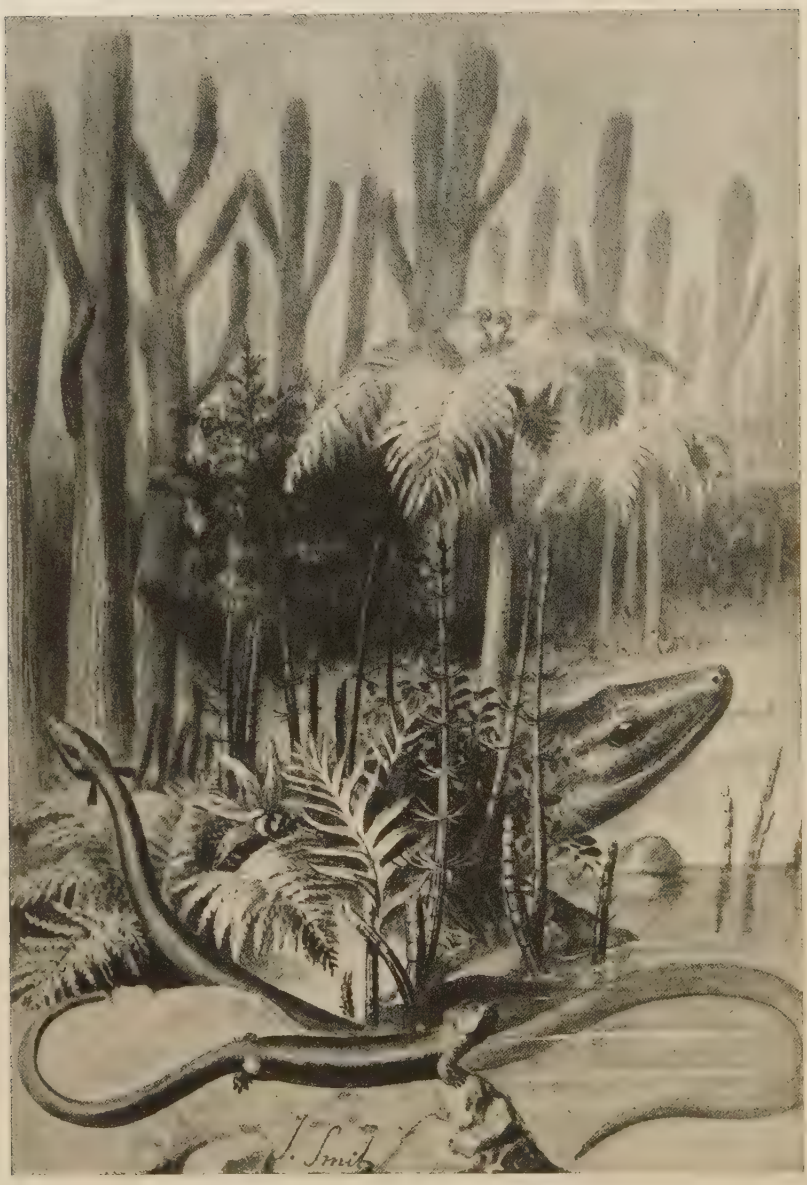


Fig. 431. — Pennsylvanian flora and amphibia, as restored by J. Smit. In the background are *Sigillaria*, with tree ferns and conifers in the middle distance. In the foreground are *Calamites* and Cycadofilicales. Amphibia are represented by a small four-limbed microsaurian (*Keraterpeton*), a large-headed form (*Loxomma*), and a snake-like, gill-bearing stegocephalian (*Dolichosoma*, from Linton, Ohio). From Knipe's *Nebula to Man.*

between the floras of the two hemispheres in the earlier half of Pennsylvanian time (see Fig. 431). In other words, the floras, and to a lesser extent the faunas, were cosmopolitan, and their similarity was undoubtedly due to equable climates and easy migration across the extensive east-west continent Eria. Their distribution was further facilitated by the fact that most of the plants had *spores*, or microscopic reproductive germs, which could be widely blown about by air currents (see Pl. 25, Figs. 4–6).

Toward the close of Pennsylvanian time these floras underwent marked changes. In Europe the older one vanished more rapidly than in America, and its place was taken by forms that became prevalent in Permian times, and some of which later reached America. The latter floras, however, still continued to be cosmopolitan in character.

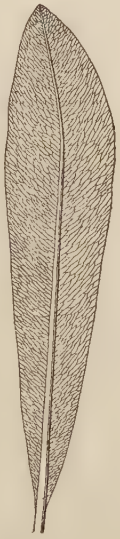


Fig. 432. — Leaf of the Permian net-veined fern *Glossopteris* (*G. indica*). From Credner's *Elemente der Geologie.*

Cool Climate Flora. — In the southern hemisphere, due in all probability to the cool climate brought about by the Permian glacial period, to be described later in this chapter, the older cosmopolitan flora was largely exterminated and a different one evolved, known as the *Glossopteris flora* because of the prominence in it of the fern *Glossopteris* (see Fig. 432). This flora was less striking, both in size and variety, than its predecessor, and less luxuriant, but hardier, and with thicker and less ornate leaves. It appeared at about the same time in Africa, South America, Australia, Tasmania, and southern India; and before middle Permian time some of the forms had attained arctic Russia. Through the commingling of the hold-over Pennsylvanian and Permian floras and their further evolution in a semi-arid climate were brought about the plant assemblages of the succeeding Triassic time. The Glossopteris flora is also known in Antarctica.

Insects. — According to Handlirsch, the Viennese authority on fossil insects, there is no evidence of these animals older than the Lower Pennsylvanian. However, there is good ground for believing that they may have arisen in the Devonian (see Pl. 22).

The size of Paleozoic insects was truly astonishing. Out of four hundred forms known from the Lower and Middle Pennsylvanian,

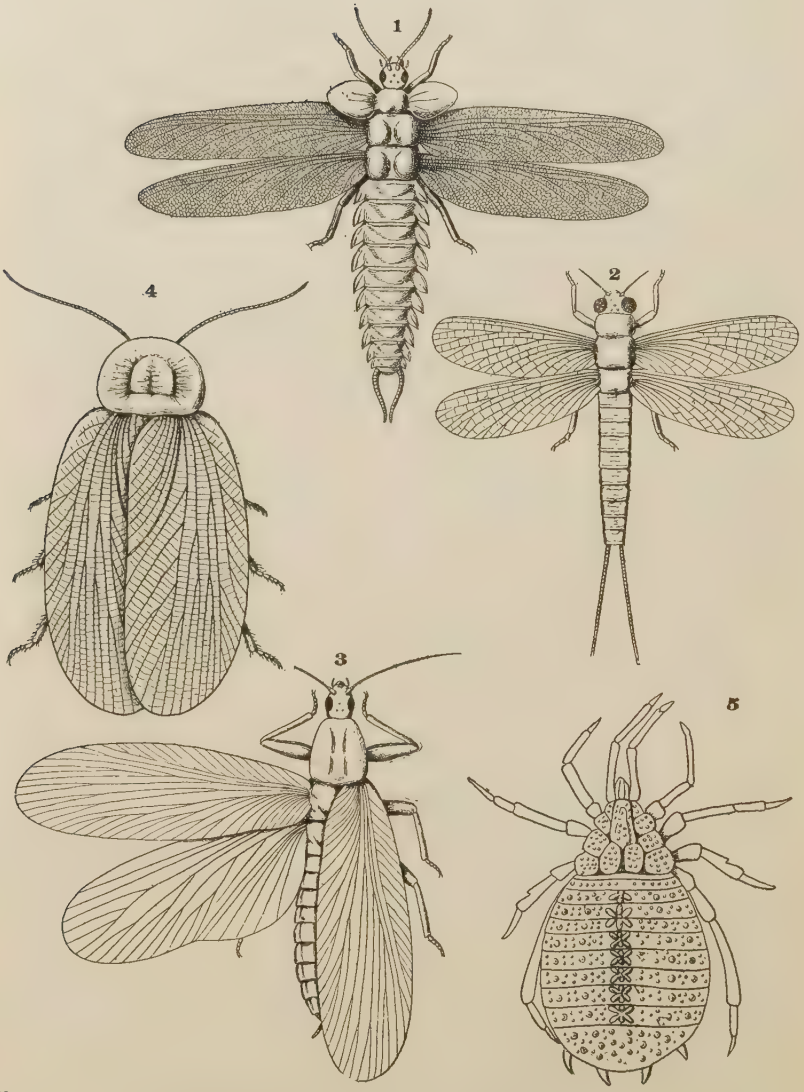


Plate 22. — Pennsylvanian insects and spider. Mainly after Handlirsch. Primal insects or Palæodictyoptera (1, 2), ancestral cockroach (3), true cockroach (4), primitive spider (5). See Appendix B.

only one had a wing length of 0.38 inch, while over twenty had a length of 4 inches, six attained to nearly 8 inches, and three to 12 inches or more, the average being 2 inches. In the Upper Pennsylvanian none exceeded 2.5 inches, and this decline in size continued throughout the Permian and Triassic and culminated in early Jurassic time. At no period since the Paleozoic have insects grown so large, and their rapid decrease in size in the Pennsylvanian, Handlirsch states, can only be connected with the colder climate of early Permian time.

The Pennsylvanian well deserves its title of the *Age of Cockroaches*, since more than five hundred kinds are known from rocks of this period (Pl. 22, Figs. 3, 4). They were mainly carnivorous, and as a rule large, several attaining a length of 3 to 4 inches. While no species were common to America and Europe, their resemblances are marked, indicating an easy land passage from one continent to the other.

There are now known about one thousand species of insects from the Pennsylvanian and Lower Permian strata. They are still scarce in the Lower Pennsylvanian, but in the middle and upper thirds of the system are common. The oldest forms, known as Palæodictyoptera, were especially prevalent in the Pennsylvanian but none lived beyond it (see Pl. 22, Figs. 1, 2). They were, as a rule, large in size and of primitive structure, and led an amphibious life, their youngest or larval stage being spent in the water. In general, they were not carnivorous animals, but as they had powerful chewing mouths it is thought that they fed on plants and on sluggish or dead animal matter. They had four straight wings, all alike, which projected sideways like those of the modern dragon-flies and could not be folded back over the abdomen as in most modern insects. The thorax had three large segments, followed by a long and slender abdomen in which the segments were alike, ending in two long cerci or appendages connected with the breathing organs, as in the living may-flies. Their eyes were compound and their antennæ simple. About 150 species are known.

These primal insects, which are thought to have arisen from the trilobites, gave rise to several transitional stocks, which in turn changed into the modern insects, such as the dragon-flies (Odonata), cockroaches (Blattoidea), and grasshoppers (Orthoptera). In most of the transitional insects the wings were still straight and not capable of being folded. The largest were the carnivorous dragon-flies, one of which, found in the Coal Measures of Belgium, measured 29 inches across the wings.

After Middle Permian time a great change took place among the insects, for the few that are known from this time are not only smaller but are more like modern forms. Judging from the insects of Triassic times, we see that those of the later Permian must have introduced complete "metamorphosis" (a transformation, as maggot to fly or caterpillar to butterfly) in their growth from the egg to the adult, and also resting stages because of winters or seasons of drought and absence of food, as is done by modern forms. This fundamental change is also attributed to the glacial period of Permian time.

Scorpions and Spiders. — In the Pennsylvanian are found scorpions, which, ancient as they are, much resemble those of modern times. Associated with them we see many forms of rather stout spider-like animals, having a distinct cephalothorax (head-trunk), and usually a large abdomen, the latter with four to nine segments; in none of them, however, are known anal spinnerets, or organs for the making of webs (see Pl. 22, Fig. 5). Those with smaller abdomens, and therefore nearer the true spiders, also occur in the Pennsylvanian rocks, but are very rare fossils.

Thousand-legs or Myriapoda appear for the first time in the Lower Old Red of Scotland and are plentiful in association with the Pennsylvanian floras of America. The average species was about 2 inches in length, but at Mazon Creek, Illinois, there lived one that had a length of about 12 inches and was 0.75 inch thick. Like the trilobites, these insects all had double pairs of legs. The head was large, and had great lateral compound eyes, in some of which there were a thousand lenses. In habit some at least were amphibious, and others appear to have been completely adapted to the land.

Land Snails. — There is no evidence of air-breathing or land snails until Middle Pennsylvanian time, when at least six species are known. The greatest number of individuals have been taken by Dawson from the hollows of fossil tree stumps (*Sigillaria*) at South Joggins, Nova Scotia. All of the species are small and are found associated with land plants in coal-swamp deposits.

Land-living Vertebrates. — In the Pennsylvanian and Permian deposits there is much evidence of the presence of many kinds of Amphibia (twenty genera) and Reptilia (forty genera), and their bones become increasingly more abundant in the strata of later times, as described in Chapter XLIV. The Amphibia are most common in the Pennsylvanian, and their origin goes back to at least the Middle Devonian. The Reptilia, on the other hand, which dominated the land of Permian time, appeared first in the Upper Pennsylvanian (see Pls. 27, 28).

The evolution of the air-breathing vertebrate life of the Carboniferous, Williston says, is the most important phase of the whole progress of evolution, for at the close of this period we find forms foreshadowing the chief groups of modern times. The predominant types of the Pennsylvanian were Amphibia, for the most part small creatures related to the living salamanders and known as *branchiosaurs* and *microsaurs*. They were rather sluggish animals living about or in the water, as is indicated by the known larval stages of branchiosaurs. They were more or less protected against their enemies by an external bodily armor, but vanished long before the close of the Paleozoic. It is among the microsaurs, however, that we find a distinct advance toward a higher existence away from

the water, and in the direction of the reptiles. Some lost the dermal armor completely and became fleet of movement, best seen in the structure of the limbs, which mimic so closely in form and structure those of the modern quick-running lizards as to be practically indistinguishable. We may be assured that some of them before the close of the Pennsylvanian were inhabitants of high and dry lands where fleetness of movement, rather than obscurity in coloration and habitat, preserved them from their enemies, and that they were crawling reptiles in everything save in some technically significant details of their palates. Specialization of the microsaurs had reached the extraordinary extent of snake-like, limbless forms.

In addition to these two types of amphibia we have two others: the temnospondylus type, in which the vertebræ are divided into separate elements, and from which the mammals eventually arose; and the stereospondylus type, which terminated in the gigantic labyrinthodonts of the Upper Triassic. (Williston.)

Of *Permian vertebrates*, by far the richest and most varied fauna known is that of America, especially of Texas and Oklahoma. It was an independent and isolated development that had no intercommunication with the reptiles of other continents until well into Triassic time. The faunistic evolution here produced striking results, but does not seem to have been the direct line into the higher and more modern vertebrate stocks.

At least three very distinct phyla of reptiles and as many of amphibia are known. Among the reptiles occur the *pelycosaurs* (*Naosaurus, Dimetrodon*), derivatives of a prior type which had branched off before the close of the Pennsylvanian; the true *cotylosaurs* (*Diadectes*), with, in some cases, singular developments of dermal carapace, or armor, strongly suggestive of the turtles and unknown elsewhere; and a third type (*Labidosaurus, Pariotichus*) of small crawling reptiles with large head, short tail, and short limbs, whose nearest, but remote, relatives are found among the pareiasaurs of South Africa. (Williston.)

Life of the Seas. — The invertebrate marine life of Pennsylvanian time was not only prolific but also very varied. It was, moreover, a cosmopolitan one, the Coal Measures faunas being everywhere very similar. In Kansas are known nearly 400 kinds of invertebrates; of shelled forms alone there are 234, divided as follows: brachiopods 46, bivalves 111, gastropods 51, and cephalopods 26. The commonest shelled animals were the spiny productids. All of this cosmopolitan life was, however, blotted out before the close of the Paleozoic (see Pl. 23).

Brachiopods are the common fossils of Pennsylvanian time, but toward the end of this period in America they were no longer prom-

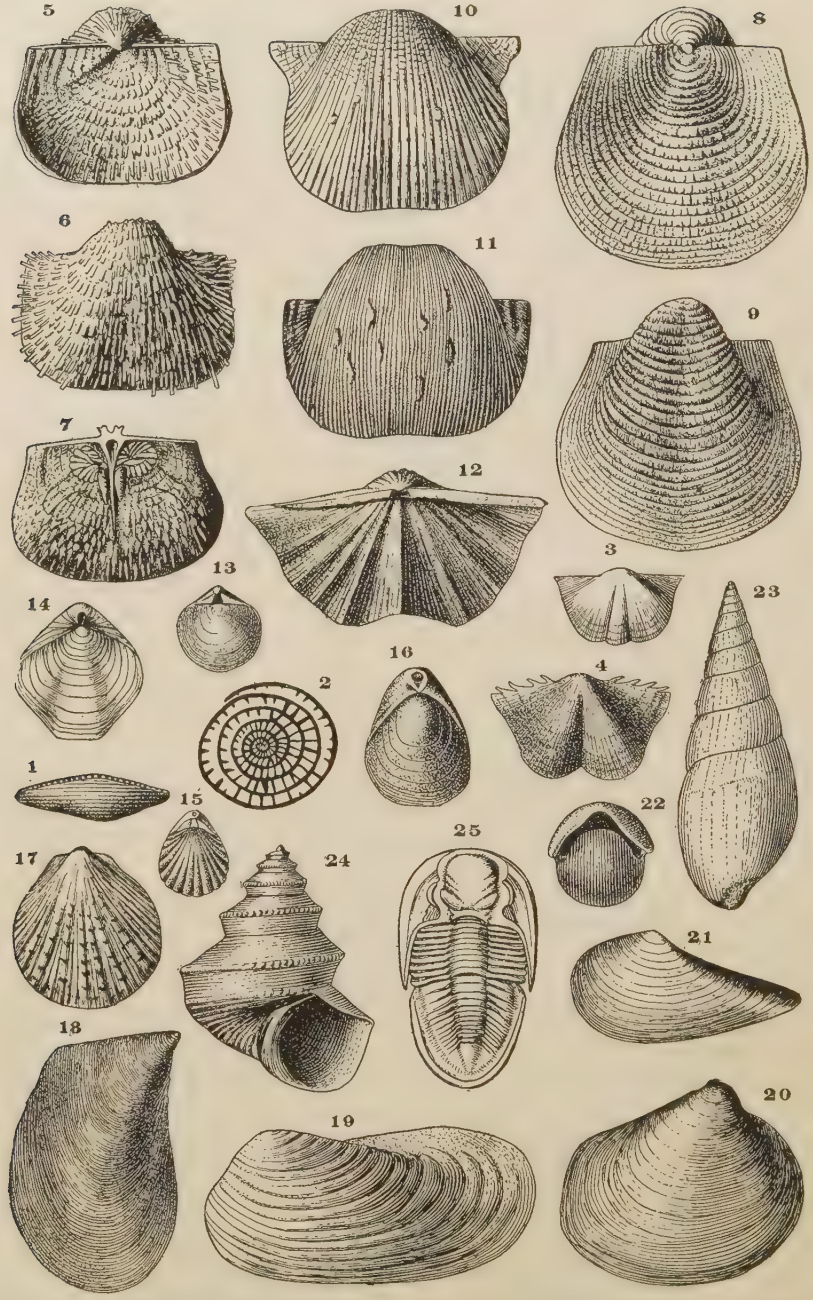


Plate 23. — Pennsylvanian Protozoa (1, 2, Fusulinidæ), brachiopods (3–16, 5–11 productids), bivalves (17–21), and gastropods (22–24), and the last trilobite (25).
See Appendix B.

inent, their places being taken by the bivalves. The same faunal change also went on in northern Europe, but in the Mediterranean region (called Tethys) extending from Sicily into India, the waters still swarmed with brachiopods into Permian time. Here the Paleozoic invertebrates made their last stand, but geologic history shows that only a few of them lived on into the Mesozoic seas. A new evolution among the brachiopods then took place, but there never again was such a variety of form as characterized the Paleozoic. While the brachiopods were vanishing, the shelled cephalopods in the goniatid and ammonid stocks were rapidly changing into a

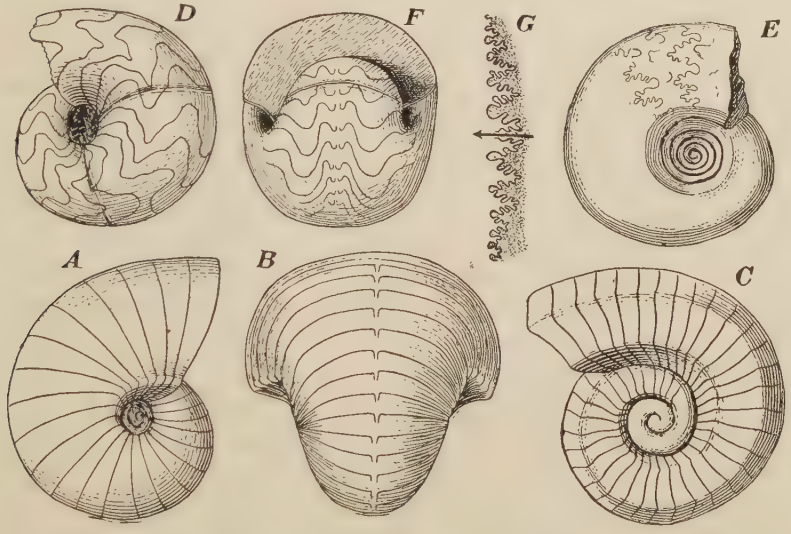


Fig. 433. — Characteristic cephalopods of the Pennsylvanian. *A–C*, nautilids; *D*, *F*, goniatids; *E*, *G*, ammonids. See Appendix B.

variety of forms characteristic of Permian times (see Fig. 433). In later chapters we shall see how these "Ammon's horns" abounded in the Mesozoic seas.

Fusulinids. — Among the minute and lowly organized animals little has as yet been said about the Protozoa, whose individual organization is contained in a single cell, and which represent the first form of animal life. These Protozoa are tiny, naked or shelled globules of streaming protoplasm, with a central, more solid sphere known as the nucleus, which is the actual seat of vital energy or life. They sometimes live singly, but more commonly are combined into colonies. They are known as fossils since the Middle Cambrian, but were not rock makers until later Mississippian time.

The forms with calcareous shells are known as the *Foraminifera*, a name referring to the numerous perforations in the shell. Of these, in the Pennsylvanian and early Permian the forms known as fusulinids (meaning *spindle-form;* the colonies look like grains of wheat) abounded on the bottoms of the seas and were often limestone makers (Pl. 23, Figs. 1, 2). They are known almost everywhere in the northern hemisphere where Pennsylvanian deposits occur. Even in far northern Spitzbergen above 76° north latitude their fossils are still abundant. Similar colonial foraminifers live to-day only on the bottoms of warm-water seas and on coral reefs.

Climate

Warm Climate of the Pennsylvanian. — According to the record of the " life thermometer " it is evident that in early Pennsylvanian time the climate was warm and humid. Great swamps in many lands of the northern hemisphere were storing vast quantities of coal — carbon taken from the atmosphere and water — and even greater amounts of carbon dioxide were being laid away in the limestones of the seas and oceans. Proof of a mild climate is found in the luxuriant coal floras, which are devoid of all evidence of a non-growing season, that is, the logs have no growth or annual rings; in the profusion and great size of the insects; in the wide distribution of the fusulinids; and in the occurrence of coral reefs in Spitzbergen. With the rise of the European Alps the floras underwent changes, and these changes were more marked in that continent than in America, for the floras and insects of earliest Permian time in the United States still indicate a climate devoid of winters, though the air was drier, the red beds and gypsum deposits pointing rather to a semiarid climate. Finally, the seas in all places lost their fusulinids, but the waters were still fairly warm in Tethys (the Mediterranean region), for in Middle Permian time the invertebrate faunas there were profuse and well developed. The cold climate of the early Permian had not yet affected the temperature of the shallower seas of the northern region, but later it is thought that even here the oceans became colder, causing a great dying out of the Paleozoic stocks of animal life. After the Middle Permian the climate of the lands seems everywhere to have been arid and semiarid and this condition lasted into Jurassic time.

Great Glacial Period of Permian Time. — For nearly fifty years geologists have described unmistakable glacial deposits of Permian

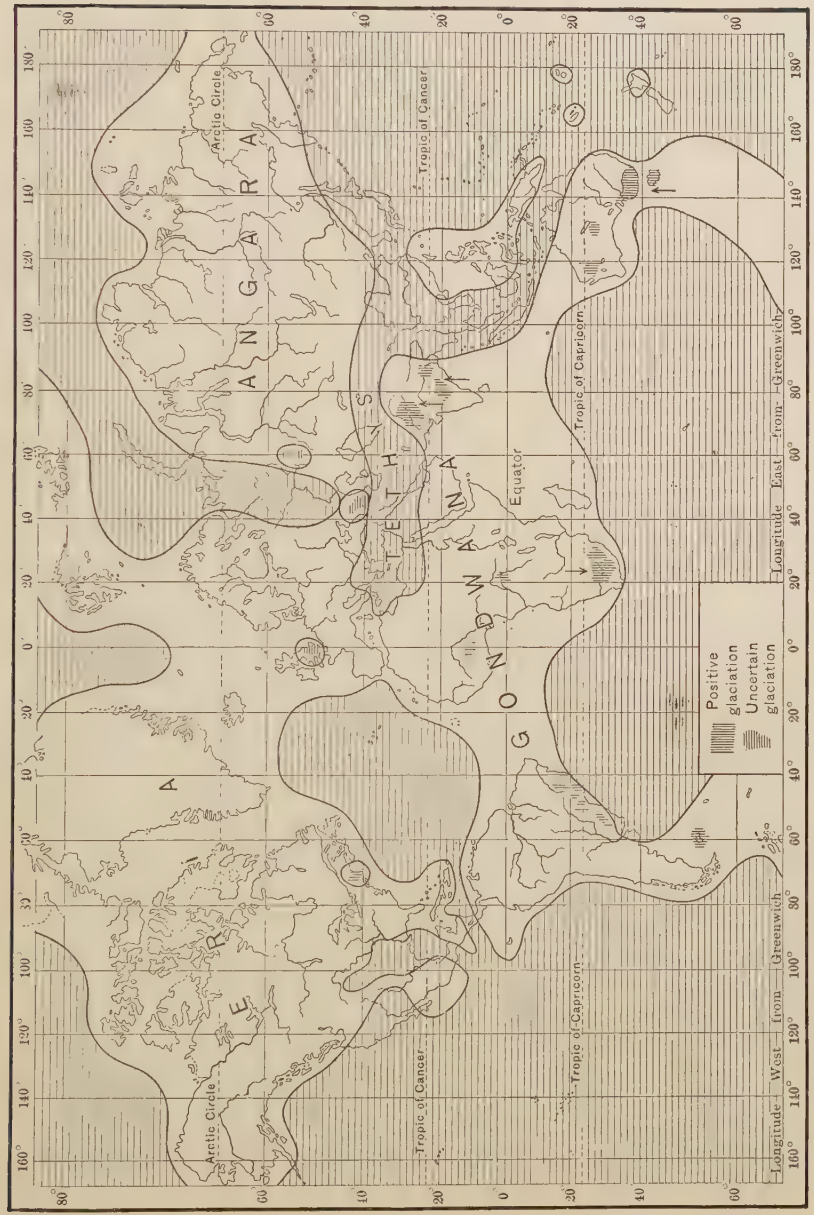


Fig. 434. — Paleogeography and glaciated areas of early Permian time. Note the transverse shape and the connected condition of the continents. Arrows indicate the direction of glacier flow. Carnegie Institution of Washington.

age in the continents of the southern hemisphere, but it is only recently that their results have been widely accepted. It is now known that glacial deposits — bowlder clays called tillites — are of wide distribution, for eight or nine such beds occur in South Australia above the Coal Measures, some of them 200 feet thick, interbedded in 2000 feet of marine strata; in Africa, the thick Dwyka series (1300 feet in Natal) extends from the southern to the central part of the continent; and in India the very thick glacial deposits (Talchir) preceded the Permian submergence. In North America, tillites seemingly of Permian age are known about Boston, Massachusetts, and striated stones have been reported on Prince Edward Island; in England and Germany also they occur at the base of the Permian. For the complete distribution of these glacial deposits, see Fig. 434.

The Permian glacial formations are found on either side of the equator from about 20° to 35° north and south latitudes, but little evidence of this kind is as yet known above 35° in north temperate lands. Further, the climate of that time was arid in the United States and in northern Europe, as is proved not only by the red beds, but even more by the great accumulations of gypsum and salt.

The evidence is now unmistakable that early in Permian times all of the lands of the southern hemisphere were under the influence of a glacial climate as severe as the polar one of recent times, and that, like the latter, the Permian one also had warmer interglacial periods, for coal beds occur associated with the glacial deposits in Australia, South Africa, and Brazil.

Cause of Permian Glaciation. — What brought about this great change in the climate of Permian time, and why it was, apparently, mainly restricted to the southern hemisphere are as yet unsolved problems. Most geologists look for the explanation in the great derangements of the air and oceanic currents brought about by the upheaving of mighty mountain chains, such as the European Alps and the Appalachians (Figs. 427 and 430). Naturally, such upheavals must have altered the outlines of the continents as well, and so brought about alterations of the oceanic currents. Even the carbon dioxide content of the atmosphere (and ocean) may have been lessened, and thus contributed further to the production of the colder climate.

Gondwana and Tethys

Gondwana, the Great Southern Transverse Continent. — Something about this continent has been stated in Chapter XXI, and now further proof of its existence must be given. Such evidence relates mainly to wide-spread deposits of Permian age which have a flora in their lower beds that has been called the *Glossopteris flora* (Fig. 432). This flora occurs throughout the southern hemisphere, and paleobotanists hold that it could only have been so widely distributed across a continuous land (see Fig. 434). Belief in the existence of Gondwana is wide-spread among European geologists, but many American workers do not yet believe in it, mainly because they hold strongly to the theory of the permanence of the oceanic basins and continents. Without this continent, on the other hand, paleontologists cannot explain the known distribution of Permian land life, and, further, its presence is equally necessary for the interpretation of the peculiar distribution of marine faunas beginning certainly with the Devonian and ending in the Cretaceous.

Tethys, the Greater Mediterranean. — To the north of Gondwana lay the great medial ocean which Suess has named *Tethys*, after the consort of Oceanus (see Fig. 434). The present Mediterranean is a remnant of this once grand middle ocean which widely overlapped northern Africa, southern Europe, and Asia, and long extended unbroken from France and Spain into the eastern Indian and Pacific oceans, from time to time connecting with the Arctic Ocean by way of the Ural geosyncline. How often it was in open connection with the Atlantic is not yet clear, but that it had such communication is seen in the similarity of certain southern European and Gulf State faunas (Helderbergian, Kinderhook, and Comanchian).

CHAPTER XLII

RISE OF THE LAND FLORAS

Plants of some kind occur in all lands and under all climates. They are not restricted to the moist soils of the valleys, but live also on the highest mountains and even sparingly in the driest deserts. In the shallow fresh waters are found many kinds of plants, and on the ocean bottoms down to a depth of about 600 feet grow the attached seaweeds. Fastened to rocks, trees, and other objects are the brown and gray lichens, a thin film of spreading plant matter. In the moist forests and on the meadows occur the fungi, including the common toadstools, plants devoid of chlorophyl and feeding on the humic material (vegetable mold) of other dead and dying vegetation. A vast variety of microscopic plants, the bacteria, live everywhere — in the soil, in nearly all waters, in the oceans, on and in other plants and animals. The yeast bacteria convert sugar into alcohol by fermentation, and are used in the making of alcoholic liquors; other bacteria are useful in the making of cheese; still others cause diseases, and are found even in all healthy organisms.

Paleozoic Floras. — From the geologic record we learn that the first known flora came into existence in the latter half of Devonian time, though a few land plants are known from the Silurian. We are probably right, however, in considering that the low-lying lands were clothed with a green verdure from the beginning of Paleozoic time, but that the early plants had not yet acquired sufficient woody tissue in their organization to be preserved in the sediments, and hence have no significance in Historical Geology. Since Middle Devonian time land plants with woody tissue have become more and more prolific and have grown to greater dimensions and higher stature, all of which means that they also have gradually attained a longer individual growth.

Swamp Life of Pennsylvanian Time. — The coal floras of late Paleozoic time are now well known and it is estimated that three thousand species have been described (see Figs. 431 and 435). Probably more than one half of this number were spore-bearing, and we may safely regard the more common plants of the Coal

Fig. 435. — Pennsylvanian swamp flora, as restored by Unger. Note the majestic *Lepidodendron* trees, with tree ferns and Cycadofilicales in the middle distance.

Measures as seedless. Many great trees were present, attaining a height of over 100 feet, with a diameter of 3 feet, and the bulk of the forest must have reared its top higher than 40 feet. It was a forest of rapid growth, of soft and even spongy woods, in which evergreen trees with comparatively small, needle-like leaves were prominent. Associated with these were thickets of rushes, also of very rapid growth, which in habit resembled the living cane brakes and bamboo thickets (Fig. 431). Here and there stood majestic fern-like trees, while many smaller ferns and fern-like plants thrived in the shady places or climbed about the trees (Fig. 435). Shades of green were the dominant color, and the monotone of the verdure was nowhere enlivened by bright flowers. Such, however, were sparingly present, but of a low order, insignificant in size, and unattractive in color. At the time when the trees and ferns were liberating their spores the entire forest was covered with a greenish-yellow or brown dust.

Spores (Pl. 25, Figs. 4–6) differ from seeds in that the latter give rise directly to sexed plants, while the former also develop into sexed ones, but these are short-lived and in turn give rise to the sexless, long-lived plants that bear the spores. In other words, the spore plants have an "alternation of generations," while the seed plants have direct development. This matter will be taken up again later in the chapter.

The air was not scented with sweet odors, for there was no honey, but it is probable that resinous smells such as pervade living conifer forests were present.

In these forests of Pennsylvanian time might have been seen flying about the largest insects that have ever lived, great dragon-flies reaching a wing spread of over 2 feet. Huge cockroaches abounded everywhere in great variety, giants of 4 inches in length not being rare (see Pl. 22). As a rule, these insects were carnivorous, and did not transfer the pollen from one flower to another as is so commonly done by living insects among present-day plants. The smaller forms were preyed upon by scorpions and spiders, the latter not making webs but living on the ground or in rotten logs, along with many myriapods, or thousand-legs. No insects of this time, so far as known, produced chirping or other sounds, and the soughing of the wind among the trees was possibly rarely interrupted save by the croak of an amphibian in the marsh. Reptiles and amphibians were common in the swamps, and it is probable that many small reptiles were running over the ground and about the trees. No larger land animals, such as we know, and no birds were to be seen.

Vascular Plants. — In this chapter we are to study only the earliest land plants, and as these can be preserved as fossils only if they have fibrous or woody material, the paleontologist is not directly concerned with the lower Cryptogams, such as the microscopic bacteria, the lichens, fungi, or even the mosses.

Plate 24. — Filicales (1, tree fern; 2–5, doubtful ferns) and Cycadofilicales (6–10). See Appendix B.

All of the higher plants above the mosses in organization are characterized by having roots, and by the occurrence in their soft tissues of what are known as *vascular bundles*. These bundles are composed of tough, hollow, interlacing fibers, whose primary function is to serve as conducting channels (hence vascular, from *vasculum*, a small vessel) through which the various food materials pass; secondarily, they are of importance as forming supporting skeletons of the plants. All of the woody material is composed of these strands, and it is this tough substance which makes it possible for leaves and other parts of plants to impress upon the sediments the traces of their former existence.

Classification. — For our purposes, Paleozoic land plants are most conveniently divided into (1) those which have no flowers but reproduce by spores and go through an alternation of generations, as explained beyond; and (2) those which have flowers and reproduce directly from seeds. Of the first subkingdom, the Cryptogams, only the phylum *Pteridophyta* will be considered; this group includes the ferns and also plants that resemble the ferns only in their method of reproduction, such as the rushes and lycopods (see Pls. 24–26). The second division, known as *Phanerogams*, embraces the seed-bearing fern-like plants (Pl. 24, Figs. 6–10), the evergreen trees or conifers, in which the flowers are small and inconspicuous (Pl. 26, Figs. 3–6), and the true flowering plants or Angiosperms.

Spore-bearing Plants or Pteridophyta

Equisetales or Rushes

Among living plants there is a small group of forms having a very wide distribution and known as Equisetales, or rushes (similar to Pl. 26, Figs. 1, 2). As a rule, they are small, less than 18 inches tall, appearing in wet places early in the year; in Central and South America and Cuba, however, a giant form occurs in groves, attaining a height of 40 feet, but with a stem that does not exceed an inch in diameter. This and all other living forms, twenty-five in number, belong to the genus *Equisetum* (see also Fig. 435).

This living genus of rushes has in the ground a non-sexed, perennial, creeping and branching, horizontal root-stalk, that at intervals gives rise to upright aërial stems and descending roots. The stems consist of a thin, externally striated, woody zone, with a large pith center. At regular intervals the stem is divided into *internodia* by transverse partitions called *nodes*, and from these arise

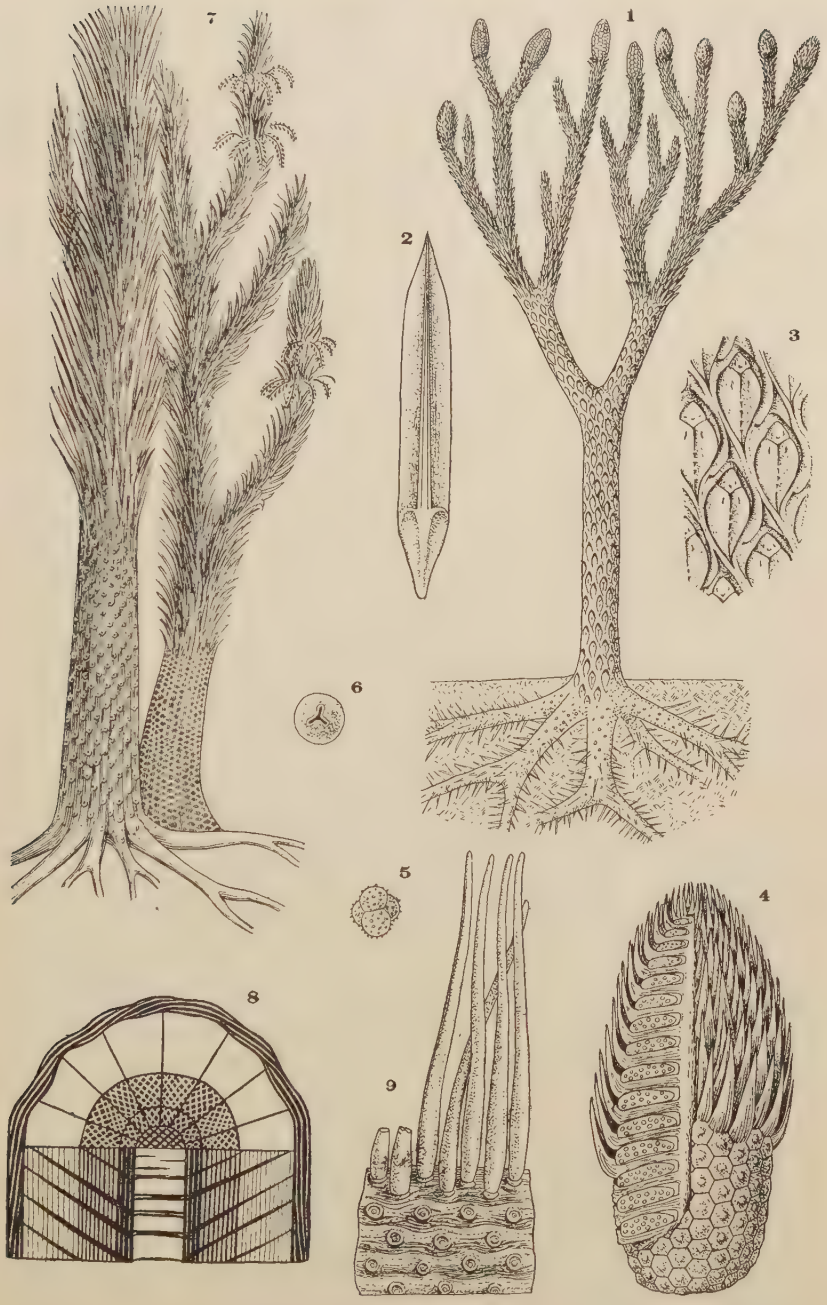


Plate 25. — Lycopods of the Pennsylvanian. 1–3, *Lepidodendron;* 4, cone with spore cases; 5, four microspores; 6, a macrospore; 7, *Sigillaria;* 8, trunk in section; 9, root or *Stigmaria.* See Appendix B.

the circles of small or reduced leaves, with one or more longitudinal veins, and also the branches when such are present. The branches repeat on a smaller scale the general features of the stems. At the top of the stem or on the branches occur the spore-bearing cones. The sexless spores, which are all alike (*homospores*), are short-lived, and give rise to small, lobate plants known as *prothallia*, or first growth, which develop both male and female organs. The prothallia give rise in turn to the fertilized egg-cell out of which grows the *Equisetum*, completing the developmental cycle from the persistent sexless generation to the sexed plant of short duration.

Fossil Calamites. — In Paleozoic time, from the Devonian to the Permian, but more especially in the Pennsylvanian, lived a great variety of other Equisetales known as the Calamites (Pl. 26, Figs. 1, 2). They were prolific plants which attained to a height of 60 and even 90 feet and a diameter of 15 inches. In them the wood cylinder was far thicker than in *Equisetum* and specimens are known having 2 inches of bark outside of the same thickness of wood. The layers of secondary wood were added externally beneath the bark, a type of growth found in modern trees. The nodes were not equidistant throughout as in the living forms, but in the earliest growth were progressively farther apart, and the stems thickened rapidly. Calamites were also far more abundantly branched than is the case in *Equisetum*, and their leaves were proportionately larger. The top of the trunk consisted of a crowded tuft of closely set circles of leaves. The cones with reproductive spores occurred more or less abundantly on the smaller leafy twigs or at the top of the main stem. As a rule, the spores were all alike, but in some cases they were differentiated into small and large types (*heterospores*, see Pl. 25, Figs. 5, 6).

Calamites occur commonly as casts of the pith cavity into which the sand of the deposits penetrated as the pith and the nodal partitions decomposed. The linear furrows seen on these casts are therefore the characteristics of the inner pith cavity of the trunk, and it is rare to find impressions of the outer side. The circles of leaves are also common fossils, and are known as *Annularia*.

Lycopodiales

Living Lycopodiales. — Lycopods is a group name for the very widely distributed, primitive, herb-like plants known as ground pines, club mosses, and running pines, the latter being extensively used in floral decorations. There are about one hundred living species of the genus *Lycopodium*, the name, from the Greek for *wolf's foot*, being given because of the appearance of the roots. In

the existing floras the lycopods never grow in dense masses to the exclusion of other plants, and therefore are not conspicuous. Their general appearance suggests the larger mosses or smallest branches of pines, since the leaves are always remarkably small.

In the Paleozoic, however, from Devonian to Middle Permian time, but more especially during the Pennsylvanian, the lycopods were the dominant plants, and attained to gigantic proportions when compared with the living representatives, for they were then at the climax of their evolution (Figs. 431 and 435). These trees in Pennsylvanian times liberated their heterosporous reproductive germs in such tremendous amounts as to be a factor in coal making (see Pl. 25, Figs. 4, 5).

Lepidodendron or Scale Tree. — Among the Paleozoic lycopods, the evergreen *Lepidodendron,* which receives its name from the scale-like appearance of the leaf-bases, was the most prominent in abundance and variety of form; upward of one hundred species have been described, ranging from the Devonian to the Permian (Pl. 25, Figs. 1–6). The trunk tapered slowly and in some forms grew to a height of over 100 feet and a diameter of 3 feet. These trees in their general appearance differed from all modern ones in that the trunk and many of the branches divided into two forks rather regularly. The more slender branches were terminated, as a rule, by linear or oval spore-bearing cones 1 to 12 inches long (Pl. 25, Fig. 4), agreeing in size and form, but not in internal structure, with the seed-bearing cones of the spruce, fir, and other conifers.

Basally, both *Lepidodendron* and *Sigillaria* (to be described later) terminated in from four to seven trunk roots that are thought to have spread almost horizontally in the ground, and there was no vertical, or tap root, continuing the trunk as in modern trees. These trunk roots each divided once or twice and tapered to a point, burrowing in every direction through the mass of decaying vegetation in the swamp. Their surface was marked by circular scars arranged in sets of five, and to these were attached round tapering appendages radiating in all directions; these latter attained a length of 15 inches and served for the extraction of food and water from the ground (Pl. 25, Fig. 9). Such roots are known as *Stigmaria* (from the Latin *stigma,* a mark), and are very frequently seen in the underclays beneath coal beds.

The leaves of *Lepidodendron* were needle-like, always comparatively small, but having a width at the bottom of 0.5 inch and a length of 6 to 7 inches (Pl. 25, Figs. 1, 2). On their under sides

there were two lateral grooves, and in these hollows were situated the minute but numerous breathing organs for the extraction of the carbon dioxide from the atmosphere. The leaves soon dropped off, and are usually found attached only to branches of small size, that is, the young growing twigs. The leaf-bases were more or less diamond-shaped, vertically elongated, and arranged on the branches and trunks in spirals, thus forming the characteristic markings of the trees. The leaf was attached in the upper part of the rhomb, and when well preserved bears three scars or pits, one of which is a vascular canal through which the plant fluids or food passed from the inner wood cylinder to the leaf, or in the reverse direction (Pl. 25, Fig. 3).

Trunk of Lepidodendron. — The structure of the trunk and branches was peculiar in that the greater thickness beneath the outer layer with the leaf scars was composed of two kinds of cork-like bark surrounding a comparatively thin internal woody cylinder that may have been entirely filled with inward growing wood or with more or less of pith (Pl. 25, Fig. 8). Secondary wood up to 2 inches thick was added to the outer cork beneath the leaf layer, and as this cork was also tough, the trees, even though tall, had considerable resisting power against the winds and storms of that time but were less stiff than the modern forest trees.

Spores of Lycopods. — The cones of fossil lycopods, while they looked much like those of modern evergreens or conifers, did not have seeds but were filled with spores (Pl. 25, Figs. 1, 4–6). The latter grew in large cases (*sporangia*) and contained either minute spores, the *microspores* or fertilizing male parts (Pl. 25, Fig. 5), or large ones, the female *macrospores* (Pl. 25, Fig. 6), often forty times larger than the microspores. These two kinds of spores were developed either in different cones or in different parts of the same cone, and there were many more of the minute spores than of the larger ones. The larger spores would not germinate in the ground until fructified by the microspores, which were washed upon them by the rain water.

Sigillaria. — Associated with *Lepidodendron* throughout the Carboniferous were other evergreen trees known as *Sigillaria,* or seal trees, so called from the shape of the leaf scars (Pl. 25, Fig. 7). Of these one hundred species have been described. They were in general appearance very much like *Lepidodendron,* but the *Sigillaria* stems were rarely branched. Trunks have been found with a diameter, just above the roots, of 6 feet, and other stems are known with a length of 70 feet and a diameter of about 2 feet at one end

and 20 inches at the other. Another specimen attained a height of nearly 100 feet and was unbranched. At the tip, for about 10 feet, these trees were clothed with erect, rigid, grass-like leaves, which in most cases were like those of *Lepidodendron*, but sometimes were far larger and wider.

The leaf scars in *Sigillaria* were arranged very differently from those of *Lepidodendron*, occurring in vertical rows with the scars of adjacent series alternating with one another. When in close juxtaposition they were more or less hexagonal in outline, but when more or less separated they appear rounded in form. In many forms the surface of the trunks was longitudinally ribbed, each of the ribs bearing a single row of leaf scars on its rounded surface (see Pl. 25, Fig. 7).

Trunk of Sigillaria. — The internal structure of the trees was very much alike in both types, but in *Sigillaria* the inner wood cylinder appears to have been thinner and the pith was of larger size. The reproductive cones reached a length of 9 inches and differed from those of *Lepidodendron* only in having a long stem for attachment. *Sigillaria* are unknown in the Devonian and died out before the close of Pennsylvanian time.

Ferns or Filicales

Nearly everyone knows what a living fern looks like, but when this knowledge is applied to the Paleozoic plants of similar appearance, even the best of botanists cannot at present be certain in many cases that the form studied is a true fern. Ten years ago it was believed that fully one half of the Carboniferous plants were true ferns and that these beautiful forms dominated the floras of that time. Due, however, to the accumulation of botanical knowledge, and more particularly to the discovery of specimens bearing the reproductive organs, it is now known that many of the so-called Paleozoic ferns bore seeds and therefore were of a higher organization and must be classified wholly apart from the true ferns or Filicales. These were the *Cycadofilicales*, plants combining the characters of ferns and cycads (plants resembling palms); they were in many ways transitional between the spore-bearing ferns and the seed-bearing plants (see Pl. 24, Figs. 6–10). Probably fully one half of the Paleozoic plants formerly regarded as ferns (about one thousand species) will eventually be shown to be seed-bearing and therefore Cycadofilicales. These are described on page 774, but to understand them it will first be necessary to study the modern ferns.

Living Ferns. — There are living to-day nearly six thousand different kinds of ferns, ranging from tiny, delicate forms to the beautiful

tree ferns of tropical lands, which grow to a height of 50 feet. The greatest variety occurs in the tropics, but they are found under all climates, even in icy Greenland. As a rule, however, ferns prefer wooded humid regions. The fern plant is the sexless generation. Its spores are usually developed on the under side of the leaves in many sori or spore-cases, a number of which are always clustered together. In each sorus there are many microscopic spores which are all alike, and these are often developed in countless numbers (see Pl. 24, Fig. 4).

A few of these spores may germinate in the ground, giving rise to a sexed plant, the *prothallium*, which is usually a primitive, heart-shaped, green shoot lying prostrate on the ground and often less than 0.5 inch in length. On its under side are developed male organs (*antheridia*) that give rise to male cells or pollen, and female organs (*archegonia*) that when fertilized by a male cell develop certain cells into sexless plants. We have here, therefore, an *alternation of generations*, that is, non-sexed plants giving rise to sexed plants, and these in turn producing the non-sexed ferns.

In the smaller herbaceous ferns there is a short, stout, underground stem that gives rise to many leaf stems, each of which develops curled up in a spiral, remaining so for a year or more. Subsequently the stems uncurl and grow rapidly into the fully developed leaves, generally called *fronds*. These may attain a great length, as in the tree ferns, and are called fronds because the leaves are compounded of many leaflets.

In the tree ferns there is but a single unbranched stem resembling a palm trunk, and the fronds, consisting of one or more leaves with their many leaflets, are developed at the top as a crown, each frond uncurling as it attains full growth. The trunk bears the scars of the fronds that have dropped off and beneath this outermost layer there is often a thick zone, the bark, which surrounds the more or less large, central, woody cylinder (Pl. 24, Fig. 5).

Fossil Ferns. — Ferns were very rare in the Devonian and are not common as fossils until the Pennsylvanian, where many species of the smaller herbaceous kinds occur associated with the tree ferns (see Pl. 24, Figs. 1–5). From the structural stand-point the Paleozoic ferns were primitive and it was in the Mesozoic that nearly all the modern forms arose.

Tree ferns became conspicuous for the first time in the Pennsylvanian and were plentiful in the later half of this period and in the early Permian. The stem in some instances attained a height of 50 feet or more, and in certain forms the fronds developed in two or four

Plate 26. — *Calamites* (1, 2) and *Cordaites* (3–6) of the Pennsylvanian. Living maidenhair tree or gingko (7). See Appendix B.

parallel columns, but in most cases they were placed spirally around the trunk. The fronds grew in crowded spirals at the top of the stem (see Figs. 431 and 435).

Seed-bearing Flowering Plants or Phanerogams

The seed-bearing plants are exceedingly varied and numerous, and are divided into two phyla. The geologically older and more primitive division is known as *Gymnospermæ* (naked seed), in which the male and female parts may be in separate flowers or combined into one, but are always inconspicuous and often without bright colors. The seeds develop in the open ovaries, which are said to be naked because the pollen falls directly upon the ovules (eggs), while in the higher plants the ovary is covered by a stigma which receives the pollen. The Gymnosperms include the Cycadofilicales, Cordaitales, Cycadales, Coniferales, and Ginkgoales.

Angiosperms. — The other phylum, which is called *Angiospermæ* (covered seed), embraces the true flowering plants. In these plants the male (anther) and female (pistil) parts are combined in the same flower, which is usually conspicuously colored. The pistil is in the center of the flower, and at the top of it is the stigma covering the ovary sac below. The pollen of the anthers falls upon the stigma and is said to pollinate it, the pollen grains then growing down through the stigma and eventually passing into the ovules and fertilizing them. Hence the seeds are said to be covered. The Angiosperms include the grasses, cereals, bamboo, palms, orchids, the forest trees and the flowering plants generally — forms unknown, however, before the Comanchian.

Cycadofilicales or Seed-bearing Ferns

In discussing the ferns on a previous page, it was stated that there were in the Paleozoic many plants having all the appearance of being true ferns but known to have borne seeds instead of spores. In other words, these plants had no alternation of generations to complete the developmental cycle but were sexed plants, either males developing pollen or females developing seeds which were fructified and developed into an embryo while attached to the plant. As the plants had the general appearance of ferns (technically Filicales) and had seeds very much like cycads, they are called Cycadofilicales (see Pl. 24, Figs. 6–10).

The seeds and pollen were borne on independent sexed plants, the fertile fronds of which were only slightly modified from the non-fertile leaves. The seeds may have been small and occurred at the tips of the leaves or hung down on the under side at the outer ends of the lobate leaves, or, if large, were attached to the thick midrib of the frond; *they never occurred in cones.* The seeds varied

in size from 0.25 inch up to at least 2 inches in length, often being long drawn out at the free end, where the entrance to the pollen chamber was located. The embryo or nut was surrounded by a husk that in some forms had a thick, fleshy exterior and a hard, stony, inner layer. Similar seeds also occurred in the Paleozoic conifers, in the ginkgos (Pl. 26, Fig. 7), and in the cycads.

Some of the Cycadofilicales had long and slender stems, and climbed about other plants; many were herbaceous, and others were as tall and stout as the tree ferns. They had their origin in primitive ferns earlier than the Upper Devonian, and their climax of development was in the Pennsylvanian and early Permian, but none are as yet known beyond the Paleozoic. The Cycadofilicales gave rise to the Cycadales so characteristic of the first half of Mesozoic time.

Genera of Cycadofilicales. — The fern-like plants now referred to the Cycadofilicales include *Lyginodendron*, *Heterangium*, most of the species of *Sphenopteris* and *Pecopteris*, and probably *Neuropteris*, *Alethopteris*, *Odontopteris* and *Dictyopteris;* also *Aneimites* with fronds as in the maidenhair fern of to-day, and *Eremopteris*. Besides these well known groups of plants there are many others that will in all probability be definitely placed among the Cycadofilicales.

Cordaitales or Large-leaved Evergreen Trees

In the Paleozoic, beginning at least with the Upper Devonian, occur logs whose structure is not very unlike that of modern pines or conifers. In the Pennsylvanian, casts of such logs are often seen in the sandstones, and in the roof shales of the coals the long strap-like leaves of these trees abound; in fact, they often form a good part of the coal. These plants, which are known as *Cordaites* (after the paleobotanist Corda), included a variety of forms, and were the dominant Gymnosperms of Paleozoic time. They were softwood evergreen trees, tall and slender, sometimes 120 feet tall and 3 feet thick. In such tall trees fully two thirds of the trunk was without branches, the upper third or fourth of the stem having a dense crown of them and abounding in simple leaves of large size (see Pl. 26, Figs. 3–6).

The leaves in *Cordaites* were always large, and some are known with a length of 6 feet and a width of 6 inches. Some were strap-shaped, with the free ends either pointed or blunt; others were grass-like, with a length of 20 inches and a width of 0.5 inch. The leaf substance was thick and had parallel veins as in the living yucca (see Pl. 26, Figs. 3, 4).

The male and female flowers of *Cordaites* were small, not over 0.5 inch in height, and the catkin-like blooms were arranged on special shoots and often

interspersed between the leaves. The male flowers developed many pollen sacs filled with pollen, while the female ones, though having many ovules, usually developed but a single one into a large seed (0.25 to 0.5 inch). The seed was enveloped in a double coat or husk, the outer layer being fleshy and the inside thinner one dense and hard.

The Cordaitales may have had their origin in the Cycadofilicales, but it is thought more probable that they developed independently out of the most ancient ferns, as did the Cycadofilicales.

While the woody trunk of *Cordaites* was very much like that of modern pines, it is distinguished from the latter by always having a central pith which may be of any diameter up to 5 inches. The new wood was formed beneath the thick bark, in other words, was added externally to the previous layers.

Cordaites was related to the conifers, but, as is seen from the above description, the two groups were very different in their composition. The former were much branched only at the top, did not have cones with seeds but developed them in catkins, the leaves were not needle-like but strap-like, and finally the trunks had a pith center. The *Cordaites* were most closely related to the ginkgos.

Ginkgoales or Maidenhair Trees

Early in Pennsylvanian time there appeared shrubs with short but broadly lobate leaves having parallel veins reminding one of the leaves of the maidenhair ferns. They also suggest greatly reduced leaves of *Cordaites*, and some of the Paleozoic forms may be shown to belong to the latter group. These plants, always rare, are not met with until the Permian, and while they never appear to have dominated any flora, their remains are found throughout the Mesozoic, and at present there is a single cultivated species living in China and Japan, known as *Ginkgo* or the maidenhair tree (Pl. 26, Fig. 7). They appear to have been most common in the Jurassic, and the living genus had its origin as early as Triassic time.

The ginkgos differ from the Cordaites at once in the much smaller and lobate leaves, while the trunks are branched throughout nearly their whole length.

Coniferales or Needle-leaved Evergreen Trees

The evergreen trees whose seeds are developed in prominent female cones and the pollen in male cones are not known to be older in origin than the Permian, but are now the commonest of Gymnosperms. The order embraces the Araucarias, the Sequoias or California "big trees" (closely related but smaller trees can be traced back to the Permian), the pine, spruce, fir, juniper, larch, cypress, and yew.

CHAPTER XLIII

COAL AND ITS OCCURRENCE IN NATURE

Carboniferous Time. — The most conspicuous feature of the rocks of Carboniferous time is the many beds of valuable coal which they contain. In North America nearly all the coal of this time was laid down during the Pennsylvanian period in the eastern United States and the Acadian provinces. In other words, the Pennsylvanian coals of North America occur east of the 100th meridian, while most of the younger coals of Cretaceous time lie in the Rocky Mountains region between this and the 115th meridian. The least valuable coals, of Tertiary time, occur west of the 120th meridian (see Fig. 438).

The more valuable coals of Europe and China were also deposited during the Carboniferous, though in Europe the accumulating began earlier and lasted longer. *By far the greatest amount of the coal in the world was laid down during the time of the Coal Measures;* it has been estimated that seven tenths of it was formed in these, the closing periods of the Paleozoic era. The names *Carboniferous* and *Coal Measures* are therefore seen to be well chosen, since this time was so essentially one of coal making. However, we should use these names only in a general way, as we have seen that this vast lapse of time is clearly divisible into at least three if not four periods.

Oscillatory Nature of the Sea. — The most striking peculiarity of the life of Pennsylvanian time was the wonderful array of plants which, as has been shown in the preceding chapter, constituted the greatest land flora of Paleozoic time, and which furnished the organic material from which the coals in the main have been made (see Pls. 24–26, also Figs. 431 and 435). The most notable physical features were the many and vast swamps, the great majority of which lay near sea-level. This sea-level was inconstant, and although its fluctuations may not have been greater than 50 feet, yet because of the vast extent of the tidal flats, the latter were widely flooded by the risings of the sea. This oscillation of the sea-level was due to the periodic subsidence of the sea floor (as explained in Chapters XX and XXI) preceding the Appalachian

Revolution, and, with every rising, the rivers were dammed back, and the waters over the flats became more or less marine, depositing muds and muddy limestones that often abound in remains of sea life (see Pl. 23). During the upwarps of the land, causing the intervals of ebb, the streams were rejuvenated, scouring away some of the deposits on the previous sea floor and spreading over the low lands the thick sandstones and sandy shales, which very rarely have marine organisms (see Fig. 437, and Fig. 42 on page 56).

Fig. 436. — Map of Cape May Peninsula, New Jersey. Dotted areas show coastal marshes, to illustrate recurrence of coal marshes in Pennsylvanian time. U. S. Geol. Surv.

At these times, and also when the sea basins had been filled with sediment, large salt- and fresh-water marshes and shallow lakes formed, around whose borders became established the marsh floras (see Fig. 436), which in time possessed the entire flats and lake areas and filled the basins with peat or jelly-like masses of carbonaceous material. These alternations between the land and the sea were repeated many times.

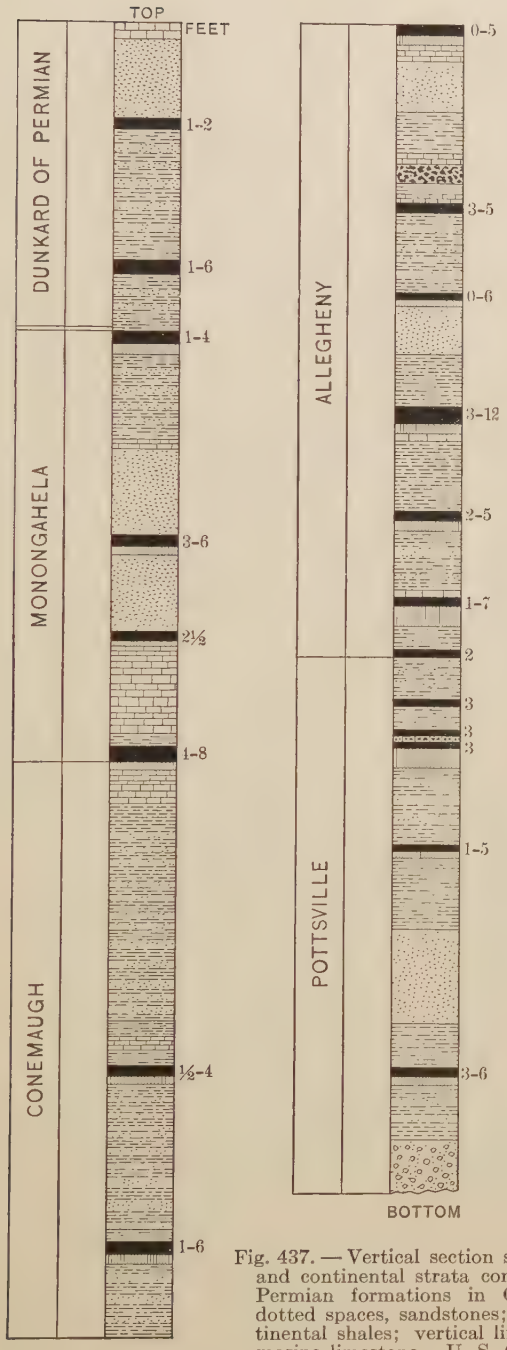


Fig. 437. — Vertical section showing character of the marine and continental strata composing the Pennsylvanian and Permian formations in Ohio. Solid black, coal beds; dotted spaces, sandstones; broken lines, marine and continental shales; vertical lines, fire-clays; block structure, marine limestone. U. S. Geol. Surv.

Pittsburgh Coal Bed. — The greatest coal swamp of Pennsylvanian time was that which made the Pittsburgh coal bed, extending interruptedly for 225 miles in a northeast-southwest direction and 100 miles from east to west. This swamp was twenty-two times greater than the present Dismal Swamp of Virginia-North Carolina; it must not be assumed, however, that all parts of the area were a continuous coal swamp, as there were undoubtedly many intermediate dry places. I. C. White states that the Pittsburgh coal is known to be workable over 6000 square miles of western Pennsylvania, eastern Ohio, and West Virginia, an area six times larger than the Dismal Swamp. The latter, before it began to be drained, covered an area 40 by 25 miles, and is now a great coal field in the making, covered with a layer of peat as much as 15 feet thick in places (see page 166, and Figs. 142 and 144). The Pittsburgh bed at Pittsburgh, Pennsylvania, has a thickness of 10 feet; in the Cumberland, Maryland, region it is 12 to 16 feet, thinning to about 6 feet at Wheeling, West Virginia, and Pomeroy, Ohio.

Variable Nature of the Strata in Coal Fields

Comparison of Different Fields. — The statements given below show very similar sedimenta-

tion in the various states, except that in Indiana the amount of material is less and there is more of mud and less of sand. The small amount of calcareous sediment in Indiana is surprising, but there is more in the Illinois area and it becomes dominant in Kansas. The twenty-five commercially valuable coal beds of Indiana have a fairly wide distribution and at least one occurs throughout the coal field of the state, but the average thickness of the coal beds is probably less than 2 feet. Some of the thicker coals average 6 to 8 feet over several hundred square miles, and one attains a local thickness of more than 10 feet. The valuable coal beds are concentrated within a thickness of 500 feet of sedimentation, with their thickest part in the centers of the various basins of accumulation.

Pennsylvania. — Broadly stated, the Coal Measures of central and western Pennsylvania, including the Dunkard of Permian age, will average about 2600 feet in thickness. To give some idea of the alternation of the strata and the amount of each kind of sediment, the following generalized statement is compiled from several sources (compare with Fig. 437):

27 zones of sandstone or sandstone and sandy shale =	1350 ft., aver. 50 ft.
20 zones of shale (rather sandy) =	748 ft., aver. 37 ft.
28 zones of impure limestone =	340 ft., aver. 12 ft.
29 zones of coal (humic) at their maximum thickness =	106 ft., aver. 3.6 ft.
11 zones of fire-clay at their maximum thickness =	56 ft., aver. 5 ft.
115 zones in	2600 ft., aver. 22.6 ft.

Indiana. — The coal field of western Indiana is the eastern part of the Illinois-Indiana basin, and while the total thickness in the western state is approximately 2000 feet, only about 1300 feet occur in Indiana. According to Ashley, the character of the sediments is as follows:

25 zones of sandstone and shaly sandstones =	708 ft., aver. 28 ft.
39 zones of shale =	408 ft., aver. 10 ft.
13 zones of limestone =	45 ft., aver. 3.5 ft.
25 zones of coal (humic) at their maximum thickness =	90 ft., aver. 3.6 ft.
19 zones of fire-clay at their maximum thickness =	53 ft., aver. 3 ft.
121 zones in	1304 ft., aver. 10.8 ft.

Illinois. — A generalized section by Worthen for northern Illinois gives ninety-five sedimentary zones having a united thickness varying between 1072 and 1722 feet. Of these nineteen are fossiliferous marine horizons, alternating with seventeen coal beds. The latter vary in depth from 6 inches to 9 feet, averaging 2 feet 6 inches, while the marine zones of shale or limestone vary from 1 to 25 feet, averaging 6 feet in thickness.

Kansas. — In eastern Kansas the thickness of the Pennsylvanian-Permian strata beneath the red beds is from 2700 to 3200 feet. The series begins with the Cherokee shales (400 to 500 feet thick) to which are restricted the workable coal beds. Then followed a long period of normal marine deposition. Occasion-

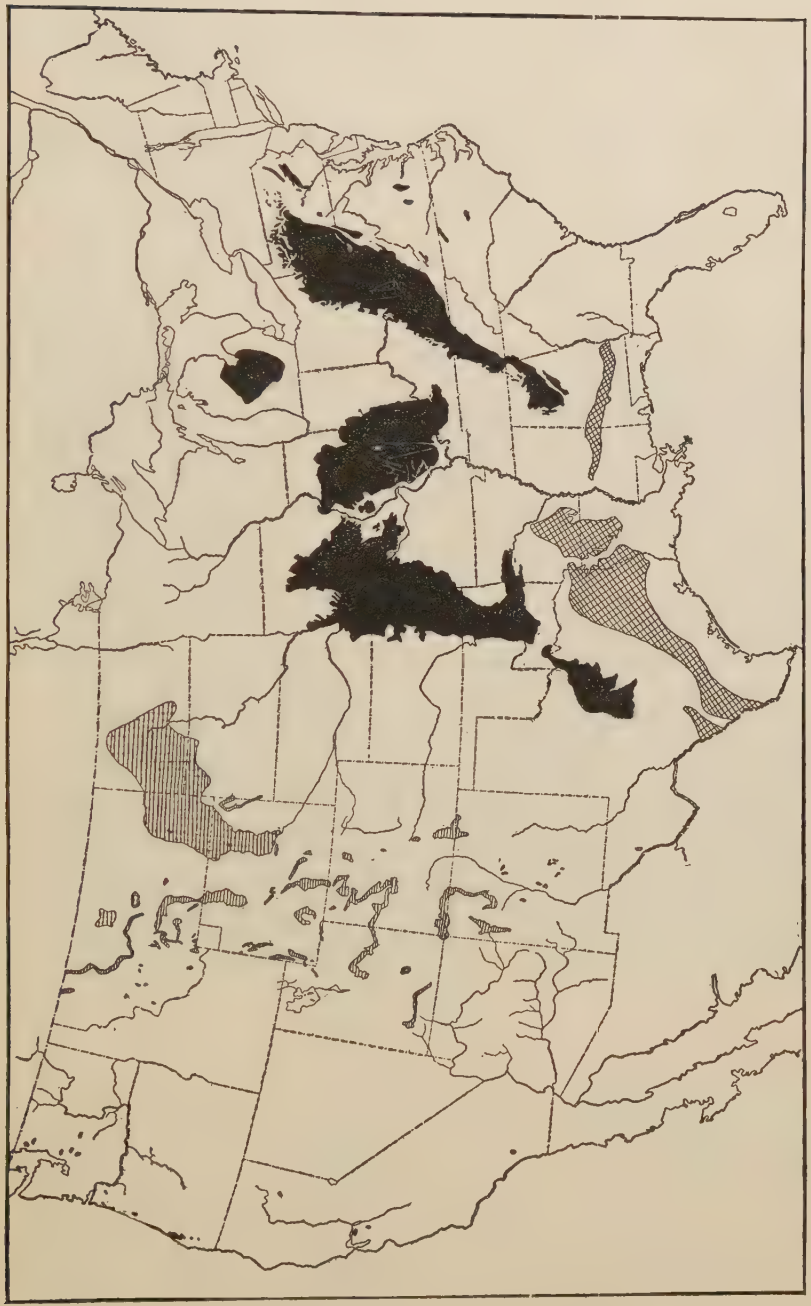


Fig. 438. — Known distribution of coal in the United States. Black areas, coals of Pennsylvanian age, except in Virginia and North Carolina, where they are of Triassic time. Areas with horizontal lines, in the Rocky Mountains country, coals of Cretaceous and Eocene age. Areas with diagonal lines, coals of Tertiary time. U. S. Geol. Surv.

ally, however, local thin sandstones with mica occur, indicating low islands, for in them are preserved land plants. In most of the shale zones are seen very thin local coal streaks of less than 1 inch thickness, which probably represent rafts or drifts of plants floated from the land.

Variability in Sedimentation. — From the above presentation it is seen that sedimentation changed often from sandstone to shale, and it is known, further, that the character of the strata also changes rapidly in its areal extent, that is, geographically. The only fairly persistent horizons are the thicker coal beds and the calcareous zones. In the Mississippi valley marine fossils occur in

Fig. 439. — A vertical *Sigillaria*, 8 feet long and 18 inches wide, rooted in an old soil, Joggins, Nova Scotia.

nearly all the shales and limestones, and as the sandstones and shales are constantly replacing one another, the phenomena presented are those of a very shallow sea, in which were developed from time to time more or less widely distributed and long-enduring salt-water marshes. It was in these marshes that the coal flora grew, as is shown by the fact that the coals of the Mississippi valley have a persistently high percentage of sulphur, a mineral substance always present in marine marshes and almost entirely absent in fresh-water ones. In the Appalachian area the

marine sediments are far less prevalent and the marshes were therefore of greater area and of longer duration.

The Joggins Section. — The Coal Measures previously described were deposits more or less under the influence of the sea. We will now turn to the celebrated Joggins section in Nova Scotia, which is of a different origin, and nearly every foot of which can be studied at the head of the Bay of Fundy.

The name Joggins seems to have had its origin in the "jog-in and jog-out" of the shore. The total thickness of the section here is nearly 13,000 feet, and it appears to be all of Pennsylva-

Fig. 440. — Another *Sigillaria* standing erect in the position of growth, Joggins, Nova Scotia. Geol. Surv. of Canada.

nian age. Throughout this mass of coarse material, very largely tinged with red, no one has yet found an assemblage of genuine marine fossils, or even a single brachiopod or other undoubted sea animal. The fossils are in the main land plants, but these are abundant only in the roofs of the coals, while the drifted and prostrate logs are nearly all restricted to the gray and green sandstones, where they occur as casts. Logan's "Division 4," with a thickness of 2539 feet, is the main fossiliferous horizon with coal formation, and often abounds in fresh-water bivalves, air-breathing

snails, bivalve crustaceans, tiny worm tubes, and bones and tracks of Amphibia; even rain-drop impressions are preserved. It is probable that the invertebrate animals seen in profusion were of brackish-water origin, but had gone farther inland over the river delta and become wholly adapted to the fresh waters. Even the swamps were, as a rule, of short duration and the more persistent ones were often invaded by muddy water which deposited above the underlying pure coals the many black shaly zones.

Fig. 441. — A vertical *Calamites* in sandstone, about 6 feet long and 3 inches wide, Joggins, Nova Scotia.

A further study of the detail of this section shows clearly that it was only the prostrate logs that were rafted away from their place of growth and whose remains are now seen as casts in the sandstones. The coals themselves, of whatever thickness, were made in fresh or brackish water marshes in the places where they now occur, since most of them are underlain by the swamp soils still filled with fossilized roots. Not only this, but there are preserved many additional soils whose exposed vegetation was swept away by the waters that brought the invading and covering muds and sands. Still further proof of the origin of the coals *in situ*, that is, where they now occur, is found in the logs of *Sigillaria* and *Calamites still standing erect in the places of their growth* (Figs. 439–441). There are many of these logs in superposed tiers, Logan reporting seventy-one such exposed in Division 4 alone (see also page 738). These standing logs have been admired by all geologists since Richard Brown discovered them in 1829 and the drawings of them by Logan, Lyell, and Dawson have been repeated in most text-books on Geology. They are of all lengths up to 25 feet, and some of them reach 4 feet in diameter. From their evidence we may agree with Lyell that what he saw in

1842 at the Joggins proved the growth *in situ* origin of these coal beds. Similar erect fossil trees are also known in England and France (see Fig. 442).

Coals of Drifted Plant Origin. — It is probable that the little coal basin of Commentry and other small coal fields in central France owe their coal beds largely or entirely to drift origin in fresh-water lakes.

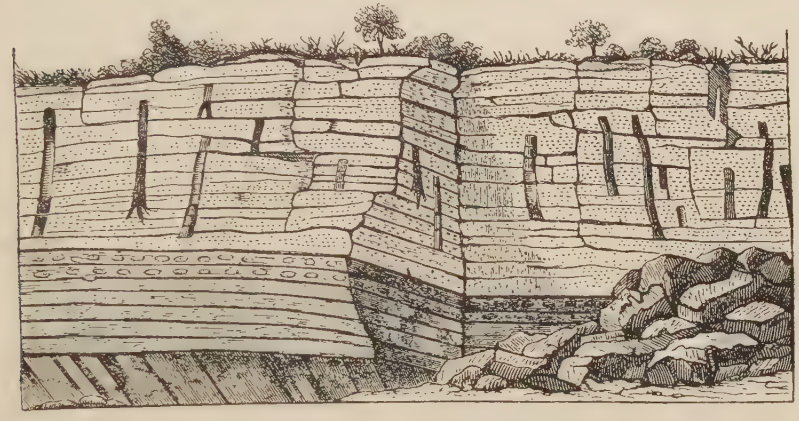


Fig. 442. — Vertical trees in the Coal Measures sandstone, St.-Étienne, France. From Credner's *Elemente der Geologie.*

Thickness of Coal Beds. — Coal beds vary in thickness from a mere film up to more than 80 feet and locally even to 100 feet. A workable bed must be at least 2 feet thick, and it is very seldom that they are thicker than 8 to 10 feet. The mammoth anthracite bed of Pennsylvania has a thickness of from 50 to 60 feet. The Pittsburgh bed of soft coal has a thickness varying up to 16 feet, with an average of 6 to 10 feet. In the Commentry basin of central France, there is a single coal bed of Lower Permian age that is locally over 80 feet thick. On one side of the basin this coal bed divides into six superposed layers separated from one another by sands and shales; this means that coal accumulated continuously in one area, while adjoining it at the edge of the basin of sedimentation there were six periods of sand inflow and deposit, each one of which was followed by one of peat storage. Toward the center of the basin sedimentation gradually ceased, and therefore the marginal separation zones of rock pinch out in that direction.

Résumé of Coal Occurrence in Nature. — As a rule, coal beds occur between coarse sediments, that is, are interbedded with sandstones and shales, and there is in the sections a more or less complete absence of marine strata and animals. Limestones may

be completely absent, and when they are interbedded with the coaly shales are thin and devoid of undoubted marine organisms. Coal beds are known to lie directly on marine limestones (crinidal in Ohio and Pennsylvania), but still there are no marine fossils even in the very basal layers of such coals. In other words, there is no transition from a pure marine fauna directly into a coal bed. Impure limestones are, however, not uncommonly seen to overlie the coal directly (Ames limestone on 18 inches of pure coal in Allegheny, Pennsylvania, Fig. 443), but the contacts are sharp and there is no transition from the coal. The roofing shales of the coals

Fig. 443. — Coal bed about 2 feet thick, directly overlain by marine limestone (Ames). Corner Woodlawn Avenue and Beaver Street, Allegheny, Pennsylvania.

generally abound in fine fern fronds, but occasionally there are very impure coaly covers that contain phosphatic-shelled brachiopods, or even sparse dwarfed marine faunas (Seville, Illinois). In all such cases these are the basal beds of the invading sea, whose water may or may not have churned up the soft peaty material and then redeposited it as a bituminous mud, along with the enclosed shells.

In the great majority of cases coals are underlain by an underclay that is usually unstratified and filled with the roots and root-

lets of plants; in other cases the roots are completely absent though such clays usually have a vertical fracture with some short and slender upright pipes still preserved, which are the casts of once existing roots. These underclays sometimes have the rooted trunks of the former forest still *in situ*, as in the Parkfield colliery, England (see Fig. 444). Underclays therefore are either old soils or the clayey bottoms of the marshes. These soils may be sandy, but are more often true aluminous clays and are then called *fireclays*. They are described at the end of this chapter.

Fig. 444. — A quarter acre of underclay in the Parkfield colliery, England, showing in diagram seventy-three stumps in their position of growth.

Conclusions Regarding the Origin of Coal. — We may conclude that coal beds, as a rule, are formed naturally in the place of their occurrence, either in fresh- or salt-water marshes. The coals of fresh-water marshes are chiefly due to growth *in situ* on river deltas, as are those of the Joggins, or rarely they may be of drifted material in lakes, like those of Commentry. These are the *limnetic coals* (from the Greek word meaning *living in a fresh-water marsh*); they are of small areal extent and of common occurrence in the Permian. Coals were also formed *in situ* on the borders of the epeiric seas or on continental shelves by plants that grew in salt-water marshes whose waters were at first brackish but eventually became fresh. These are the *paralic coals* (meaning *growing by the sea*), often of wide areal extent; they embrace essentially those of Pennsylvanian time. The great purity of many coals is further evidence of their having formed where found, for if made of drifted plants, the water currents bringing the latter must of necessity have also carried muds or even sands, which would have been deposited with the organic matter.

Sulphur in Coal. — The amount of sulphur in coals of Pennsylvanian age is very variable, from a trace to nearly 9 per cent. The average amount in ten anthracite coals from eastern Pennsylvania is 0.6 per cent (0.4–1.0); in seventy-seven bituminous coals from the western part of the same state it is 1.4 per cent (0.4–5.8); in twenty-four soft coals from Ohio it is 2.2 per cent (0.4–6.3); and in the Indiana-Illinois coals, nineteen samples averaged a little over 2.0 per cent (0.3–4). The anthracite coals of Pennsylvania and the bituminous ones of the

Joggins field appear to be wholly of fresh-water origin, since no marine fossils are known in the associated strata, and they have the smallest amount of sulphur. All the other coals are interbedded with strata having more or less of marine faunas, and as these coals are of marshes that were often somewhat under the sea-water, where the sulphur-making bacteria were most abundant, the sulphur content is accordingly far greater. Hydrogen sulphide is found in great abundance in peat beds to which sea-water has access, according to C. A. Davis, and is seldom found in peat formed under fresh water.

Pennsylvanian Coal Fields of America

The oldest coal fields in America, of which there are six (Acadian, Rhode Island, Appalachian, Michigan, Eastern Interior, Western Interior), occupy an area estimated at over 252,000 square miles, a total considerably greater than that of any other continent in the world (see map, Fig. 438). China has the next largest area, in amount somewhat less than that in the United States. Russia has 27,000 square miles; New South Wales, Australia, 16,500; Great Britain, 9000; Germany, 3600; and France, 1800.

1. **Acadian Coal Field.** — The productive area of this coal basin lies on both sides of the Bay of Fundy, along the south shore of Northumberland Strait, and in Cape Breton, and is estimated at about 18,000 square miles. The eastern rim of the basin is in southwestern Newfoundland, where coal beds occur, some of which appear to be valuable. The thickness of the series rises to 13,000 feet and it is somewhat folded.

2. **Rhode Island Coal Field.** — The smallest coal basin, with an area of but 500 square miles, occurs in Rhode Island, extending a little into Massachusetts. The strata strike north-south, with a total thickness of 12,000 feet, and often rest on formations of Cambrian age. The coal is of fresh-water origin, highly anthracitic, or, rather, graphitic, and because of the small amount of volatile matter in it will not burn unless mixed with another coal. This change has been produced by metamorphism, due to the great deformation during the Appalachian Revolution and to the intrusion of large granitic masses.

3. **Appalachian Coal Field.** — This great field is divided into (a) the *anthracite* field, and (b) the *bituminous* or Appalachian field proper. The anthracite field is confined to eastern Pennsylvania, with a productive area of 484 square miles, limited to synclinal basins striking northeast-southwest. The strata of the adjacent anticlines, with their coal beds, have been worn away. This is the most thoroughly developed field.

The Appalachian bituminous field is the second largest and by far the most valuable one in America, extending through nine states, from the northern border of Pennsylvania and eastern Ohio southwestward 850 miles to central Alabama. The basin lies between Appalachia and the Cincinnati uplift, and contains approximately 70,800 square miles, of which about 75 per cent holds workable coal. In general the strata are either gently undulating or essentially horizontal, with the thickness of the formations, as well as the thickness and number of the coal beds, increasing toward the east.

4. **Michigan Coal Field.** — An isolated oval basin is confined to the southern peninsula of Michigan, with an area of approximately 11,000 square miles, whose

strata are thickest in the center of the field. All prospecting for the bituminous coals is done by the drill, because the region is deeply covered by glacial material.

5. **Eastern Interior Field.** — An isolated coal basin lies to the east of the Ozark mass and west of the Cincinnati uplift, in the states of Indiana, Illinois and western Kentucky. It has an area of 58,000 square miles, of which probably 55 per cent is productive with present methods of mining. In general the coal mined is of the soft bituminous type. The deposits of this basin in the northwest are connected across Missouri and Iowa with the Western Interior field.

6. **Western Interior Field.** — This is the largest basin, and lies to the north and west of Ozarkia, extending from northern Iowa and Nebraska southwestward 880 miles to central Texas. It also has an eastern extension south of the Ozark mass from central Oklahoma into Arkansas. Here the deposits are also the thickest, are somewhat sharply folded to the north, and form the northern border of the Quachita Mountains. The area of the deposits is about 94,000 square miles, but less than half of it is coal-bearing. In the northern portion the coal is bituminous and fairly uniform in composition. In the southwestern portion the coals vary from soft bituminous to semi-anthracite (Arkansas). To the west the basin is overlain by Permian and later formations.

Composition and Varieties of Coal

General Statement. — On pages 164–169 an explanation is given of how peat accumulates; now we must consider how the plant material comes to be changed into coal. The process is one of *carbonization*, the degree of perfection being due to a slow alteration in the amount of the volatile or organic combustible matter in the course of geologic time. The result is coal in one of its many varieties, depending on the amount of fixed and volatile matters present. The change in the amount of volatile matter is brought about through its loss in the form of gases, chiefly as water vapor and carbon dioxide. This loss of the hydrocarbons seems to be due, in the main, to pressure of the superincumbent strata (load), or that produced by their folding during the time of mountain making. The gases then escape either through the pores or the cracks (joints and cleavage) in the strata, but the success of this escape is again dependent upon the presence of overlying shale beds and their internal construction (grain). In general, the shale beds are impervious to the gases and the circulating ground waters, but when sandy or cleaved through deformation, the chances of escape are greatly enhanced, resulting in anthracite coals that are 95 per cent fixed carbon.

Proofs of the Derivation of Coal from Plants. — We have seen that coals, as a rule, lie upon clays filled with roots, and even upon the floors of the former forests. In the roofing shales of coals are to be seen well-preserved fern fronds and the woody stems of many kinds of plants. Many of these stems are covered with a

film of coal like that of the coal beds. In the coal itself it is common to see thin zones of impure coal, the worthless *bony coal* of miners; this is more or less mixed with clay, the result of coal formation where the marshes were invaded by water currents bringing in mud, and such zones always show plant remains and often very good ones (see Fig. 445). In fact, in almost any coal, even the anthracites, when allowed to weather, we may see plant fibers.

Good specimens of *Lepidodendron*, *Sigillaria*, and *Calamites* may be had along some of the bedding planes of the coal. They occur also in the textureless cannel coal (described on page 792), as in Breckenridge County, Kentucky, where the coal is marked through its whole mass by stems and leaves of *Stigmaria* and *Lepidodendron* rendered distinct by infiltration of sulphuret of iron. Even when nothing of an organic nature is discernible to the unassisted eye, the plant composition of the coals can be made out if suitably prepared thin sections are studied under the microscope. Finally, even the ashes will show vegetable cells.

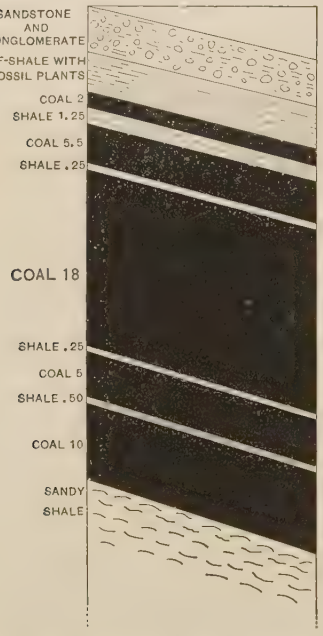


Fig. 445. — Coal bed with zones of shale (bony coal), Prague, Bohemia. Thicknesses given are in inches. From Toula's *Lehrbuch der Geologie.*

Le Conte has truly said that "a perfect gradation may be traced from wood or peat, on the one hand, through brown coal, lignite, bituminous coal, to the most structureless anthracite and graphite, on the other, showing that these are all different terms of the same series. In chemical composition, too, the same unbroken series may be traced. Lastly, the best and most structureless peat, by hydraulic pressure, may be made into a substance having many of the qualities and uses of coal." The formation of peat, a knowledge of which is so necessary to a proper understanding of coal formation, is explained on pages 164–169.

Animal Material in Coals. — Fishes, amphibia, and certain kinds of invertebrate animals are at times found in some abundance in certain coals (Linton, Ohio, Fig. 431) and there can be no doubt that their decomposed remains have yielded considerable carbonaceous material to the peaty or more volatile varieties

Varieties of Coal. — The varieties of coal depend upon the *purity*, the *degree of carbonization*, and the *proportion of fixed and volatile matter*. Following for the most part the definitions of Le Conte, they may be classified as follows:

Varieties Depending upon Purity. — Coal consists both of organic or combustible, and of inorganic or incombustible matter. On burning, the organic combustible matter is consumed, and passes off as gases, chiefly water-vapor and carbon dioxide, while the inorganic incombustible matter is left as ash, composed mainly of silica, carbonate of potash, etc. The relative proportion of combustible matter to ash may vary to any extent, good coals having from 1 to 5 per cent ash. A coal having from 30 to 40 per cent ash is called *bony coal*, and is the valueless refuse of the mines.

Again, all living vegetable tissue contains incombustible matter, which, on burning, is left as ash, the latter amounting to an average of about 1 to 2 per cent. But, as in the process of change from woody tissue to coal much of the organic matter is lost, and the relative amount of ash is thereby increased, we may say that if a coal contains 5 per cent or less ash, it is absolutely pure, that is, its ash comes wholly from the plants from which it was made; but if a coal contains more than 10 per cent ash, it is probably impure, that is, it was mixed with mud or clay at the time of its accumulation.

Varieties Depending upon Degree of Carbonization. — The previously mentioned varieties consist of *pure* and *impure* coals; these consist of *perfect* and *imperfect* coals. We find the vegetable matter, accumulated in different geological periods, in different stages of that peculiar change from woody tissue into peat, and this into coal, called *carbonization*. Brown coal and lignite are examples of such imperfect coal. They are always comparatively modern.

Varieties Depending upon Proportion of Fixed and Volatile Matter. — Coal, even when pure and thoroughly carbonized, still consists of many varieties, having different uses, depending upon the proportion of fixed and volatile matters. These are the *true* varieties of coal.

In pure and perfect coal, then, the combustible matter is part fixed and part volatile. These two kinds of matter may be easily separated by heating the coal to redness in a retort. By this means the volatile matter is driven off and may be collected as tar, oil, etc., in condensers, and as permanent gases in gasometers, and the fixed matter is left in the retort as coke. The proportion of these may vary greatly in different coals, and so affect the uses to which the coal is applied. For example, when the coal consists wholly of fixed carbon, it is called *graphite*. This is not usually considered a variety of coal, because it is not readily combustible, but it is evidently only the *last term of the coal series*.

When the combustible matter of the coal contains 90 to 95 per cent fixed carbon it is called *anthracite*. This is a hard, brilliant variety, with conchoidal fracture and high specific gravity. It burns with almost no flame — the bluish flame of carbonic oxide — and produces much heat.

If the combustible matter contains 80 to 85 per cent fixed carbon and 15 to 20 per cent volatile matter, it becomes *semi-anthracite*, or *semi-humic coal*, of various grades. It should be understood that not all of the volatile matter is combustible and a classification of coals has been made on the basis of the ratio of combustible volatile matter to the fixed carbon. These semi-anthracites are free-, rapid-burning coals, producing a long flame and high temperature, because

they do not cake and clog. They are admirably adapted for many purposes, but especially for the rapid production of steam, and hence are often called *steam coals*. The yellow flame produced by this variety is due to the burning gas of the coal, which is almost wholly a compound of carbon and hydrogen, a hydrocarbon.

If the volatile matter rises to the proportion of 30 to 40 per cent, the coal becomes a typical *humic* (from humus or vegetable mold) coal, which always burns with a strong bright flame, but often cakes or tends to coke. This is perhaps the commonest kind, and may be regarded as typical coal. It is one of the "bituminous coals," but as this word is misleading, coals not being composed of bitumen, humic is preferred.

If the volatile matter approaches or exceeds 50 per cent, a high proportion of which is combustible, a highly fat *humic* or *fusing coal* is formed. This variety is especially adapted to the manufacture of gas and coke.

In addition there are other varieties depending on physical characters. Thus, for example, *cannel coal* (a corruption from "candle coal," so-called because it burns readily with a candle-like flame) is a dense, dry, structureless, lusterless (sapropelic), black type which breaks with a conchoidal fracture. It usually affords the largest proportion of combustible volatile hydrocarbons and is valuable for gas making. When the supply of petroleum and natural gas gives out, these coals will be much used in the making of substitutes for them. Cannel coals occur in Ohio and Indiana and abundantly in eastern Kentucky, and it is in them that fresh-water animal remains at times are plentiful. The cannel coals are thought to owe their fatty nature to the kind of plant material of which they are composed, mainly lycopod spores, and to their conversion into jelly-like masses by bacteria in fresh-water marshes.

Origin of the Varieties of Coal. — The formation of peat from woody tissue, or cellulose, together with the chemical changes involved in the process, has been previously discussed, page 164. It was there shown that the essence of this change consisted in the removal of most of the oxygen with some hydrogen and carbon as gases — water-vapor, marsh gas, and carbon dioxide. The continuing removal of these, especially the last two, from peat tends to raise the percentage of fixed carbon and to convert it into coal of the more humic varieties. The question then arises as to the origin of the anthracite from these more humic coals.

Anthracite differs from bituminous coal in having more fixed carbon and less of the volatile hydrocarbons. It is well known that volatile matter is constantly escaping from coal, and that the gases thus released may become ignited, causing explosions in the mines. If the volatile matters had been constantly escaping during geologic time we should expect all of the oldest coals to be anthracitic, which, however, is far from being true. On the other hand, *anthracite* is almost invariably *found in strata that are more or less folded*, as in the anthracite field of Pennsylvania (see Fig. 446), and when the strata are much deformed the coals are graphitic, as

in Rhode Island. Because of these occurrences it has long been assumed that the mountain-making forces have in some way brought about the change, but as to the exact process geologists are not yet agreed.

We have seen that coal beds are nearly always covered by a shale zone, and when studying the accumulation of petroleum and natural gas we also learned that these pools always occur more or less directly beneath an impervious shale formation. In stratified rocks where coal occurs there is not one single coal bed but many of them, and there are always far more shale zones than coal beds. We have further seen that in the Ohio-Pennsylvania-West Virginia area there are ten horizons of valuable oil in the sand-

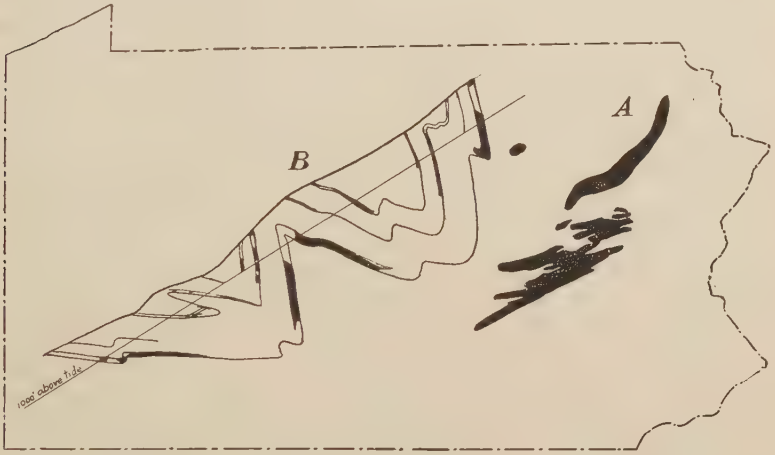


Fig. 446. — *A*, anthracite coal areas in Pennsylvania. *B*, vertical section across the Panther Creek basin in the anthracite region, showing folded nature of the coal beds. U. S. Geol. Surv.

stones. Therefore, we may conclude that *the volatile materials of coal beds and of marine formations are kept, as a rule, from escaping at the surface of the earth by the shale layers.* That volatile materials are constantly escaping at the surface in some localities, however, is proved by the occurrence of burning springs, oil seepages, and asphalt lakes. It should be added here that most of these hydrocarbons are thought to be derived out of the marine strata and not out of the coal beds. In places, a semi-asphaltic material called *albertite*, and looking like bitumen or asphalt, occupies rents in the rocks, instead of constituting layers. A similar substance, called *grahamite*, occurs under like conditions in the Coal Measures of West Virginia. Both are supposed to have been

made from the oxidation of mineral oil, that is, are of animal origin and derived from marine formations.

In mountain-making processes it is well known that shales stretch far more than sandstones and limestones and do not pull apart so readily, forming rents. However, when the deformation is marked, all of the rocks are much cleaved and this cleavage is well shown in the roofing slates of mountainous regions. Further, no oil and gas accumulations of commercial value occur in the mountain belts of ancient origin, but it is in these areas that the anthracite coals are found (see Fig. 446). What more natural inference than that the anthracitic and graphitic coals have lost their volatile hydrocarbons, not so much through the pressure engendered during the time of mountain making as by the cleavage and shattering of the strata above, thus permitting the oil and gas, in the course of time, to escape?

Wastage of Coal in Mining. — The amount of impure coal in nearly every coal bed in the United States varies from 10 to 50 per cent, averaging 25 per cent. At present all of this is thrown away, though much of it could be used for the making of gas for gas engines. Due to faulty mining, bad engineering, the falling of roofs, "squeezes," "creeps," and "crushes," approximately another 25 per cent of the coal present in the mines is never taken out and is thus lost. In other words, about 50 per cent of the coal present is wasted or unused and never to be regained. The wastage in a mine is anywhere from 40 to 70 per cent. "If the wasteful methods of the past are to continue," says I. C. White, "if the flames of 35,000 coke ovens are to continue to make the sky lurid within sight of the city of Pittsburgh, consuming with frightful speed one third of the power and half of the values locked up in these priceless supplies of coking coal, the present century will see the termination of the American industrial supremacy in the iron and steel business of the world."

Value of Coal Mined in the United States. — In 1912 the soft coal mined in the United States amounted to 450,000,000 short tons, valued at $518,000,000. The anthracite output of Pennsylvania for the same year was 75,000,000 tons, valued at $177,000,000. In 1913 three-quarters of a million men were employed in the mining of coal. From 1814 to the end of 1900 the United States had produced 4,470,000,000 short tons of coal, and by the end of 1912 the total had risen to 9,270,000,000 short tons.

Iron-ores and Fire-clays of the Coal Measures

Iron-ores. — In places where coal beds abound one rarely sees red or yellow rocks. The color is generally gray to light greenish, or even whitish, for the sandstones, while the shales, though they may be greenish to black above the coal beds, are usually more or less white clays beneath them. This lack of strong red and yellow colors, which are produced in rocks by ferric oxide (hematite and limonite), is due to the fact that in the presence of organic matter, either in the coals as they were deposited or in the solutions passing downward from them, the ferric iron is reduced to ferrous and then unites with carbon dioxide to form ferrous carbonate. The latter is not a coloring agent and by this change, whose chemical aspect has been previously discussed, page 161, the strata are decolorized except as they may be gray to black from included carbonaceous material. As shown on pages 161 and 170, the ferrous carbonate thus formed, being, like carbonate of lime, soluble in water containing carbon dioxide, may be removed in solution, leached out and concentrated elsewhere. By passing into shallow bodies of standing water the carbon dioxide might escape, the iron be re-oxidized by the aid of the iron bacteria and precipitate as hydrated ferric oxide (limonite), forming the so-called *bog iron-ore.* But in the presence of abundant organic matter, such as the swamps and marshes of the Carboniferous time possessed, this re-oxidation was prevented and the iron concentrated and deposited as the ferrous carbonate. Sometimes the iron-ore was mixed with more or less clay from muddy water and this variety is known as *clay iron-stone;* in other cases it was more or less mingled with black peaty matter, in those swamps where there was prolific vegetation, and this forms the valuable *black-band ore,* which occurs in Ohio and Pennsylvania.

These iron-ores are found in beds of any thickness up to 50 feet, but are usually under 4 feet, and like the coal beds may be repeated many times in a section. They are also often underlain by fire-clays, or the iron-stone concretions occur in the clays.

Fire-clays. — Fire-clays, when impure, are more or less sandy, but are usually aluminous. The aluminous type is the true fire-clay, and is so named because it is capable of resisting heat to a high degree and is much used for making fire bricks to line the insides of blast furnaces. The purest white clays are used for the making of pottery and tiles. The purity of these white clays is due to the presence of carbonic acid in the depositing waters, which takes away the iron and also the particles of feldspar which it decomposes. When some of the feldspar still remains, furnishing soda, potash or lime to act as fluxes, the clays are fusible and are not good fire-clays.

CHAPTER XLIV

THE EARLIEST LAND VERTEBRATES

In the Middle Paleozoic, after the lands had been clothed by plants, there thus became established a habitat capable of sustaining animal life, and destined to be mastered by several stocks of invertebrates and dominated by vertebrates. Among the backboned animals, the first inhabitants of the dry land were the Amphibia, whose short reign lasted only through the Devonian and Mississippian. Then came the longer dominance of the Reptilia, which began their ascendancy in the Pennsylvanian and ruled the lands and even the seas until the close of the Mesozoic. To understand this evolution, it is now necessary to study the organization of these two types of animals.

In Chapter XXXVII are described the structure of fishes, their relationship to one another, and their probable evolution from the invertebrates. Chapter XXXIX sets forth how the probable rise of the fishes took place under the stress of arid climates, which brought about the change from the ancestral marine half-vertebrates into air-breathing fishes. It is immaterial to our further study of the vertebrates whether or not this evolution took place exactly as there described; the fact remains that the oldest known vertebrates occur in estuarine deposits or in those of fresh water, and not in normal marine sediments. Further, air-breathing fishes occur only in fresh-water deposits of Devonian and later time, and in none of the seas and oceans of the present time do air-breathing animals exist, other than those that have come from land-living ancestors, such as the porpoises, whales, and seals. This evidence is clearly indicative that lungs did not originate in the sea. The only possible place, then, where they could have arisen was in waters of an evanescent character, that is, in streams and lakes which periodically dried up under a semiarid climate. The lung-fishes were still animals distinctly habituated to the water, but prophetic of the coming of higher vertebrates, and in the present chapter this further evolution will be traced. Before doing so, however, it will be necessary to understand the structure of the living Amphibia and their developmental stages from the

egg to the adult. Thomson says that amphibians are those vertebrates which made the transition from aquatic to terrestrial life, but almost all have lagged near the water. In many ways they are more closely related to the lung-fishes than they are to higher vertebrates. After the amphibians the next step will be to learn the organization of some of the living reptiles, and with this general information about both it will be easier to understand the more primitive Amphibia and Reptilia of later Paleozoic times.

Amphibia, Living and Fossil

Amphibia differ from fishes in having legs and not fins, each leg bearing fingers or toes. Nearly all of them breathe by gills when very young and may retain these organs throughout life; lungs

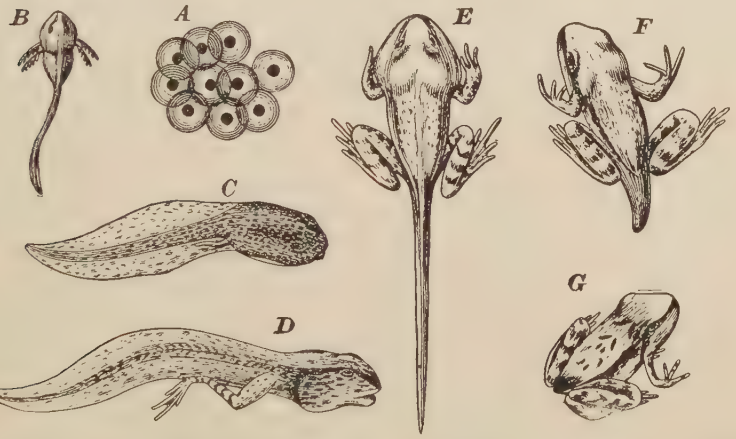


Fig. 447. — Development of the frog (*Rana temporaria*). *A*, eggs, greatly enlarged; *B*, tadpole or polliwog, with two pairs of gills; *C*, tadpole with first indication of hind legs; *D*, older tadpole; *E*, tadpole with both pairs of legs free; *F*, *G*, stages in which the tail is resorbed. Redrawn from Leuckart's wall charts.

are, however, nearly always present in the adult, although among the salamanders they may be reduced to vestiges or completely suppressed (see Pl. 27, Figs. 1–4).

Living Amphibia. — There are about nine hundred forms of living Amphibia, most of which are of the frog kind (Fig. 447). Frogs, toads, newts, sirens, mud-puppies and land salamanders are types of living amphibians (Pl. 27). All are cold-blooded animals. The class name Amphibia, which means *living a double life*, was given them because many live both on the land and in the fresh water. Others, however, live entirely in the water, and, as a rule, all

amphibians in their younger stages are wholly restricted to this element.

The sexes are always separate and in the great majority of species the small eggs are fertilized in the water and develop there without further care from the parents. The development is, therefore, very much the same as in the fishes and very unlike that of the higher vertebrates. The eggs of frogs and toads, for example, develop into little animals commonly known as tadpoles or polliwogs, with a more or less large and rounded head and body terminating in a long and very flexible tail, which they wriggle in swimming, as do the fishes (see Fig. 447). These tadpoles have gills which at first project from the sides of the head, but are later covered by an operculum. In about two months they attain a stage which is the equivalent of the lung-fishes. They then undergo a marked metamorphosis, the hind legs appearing first and later the front pair, which are hidden under the operculum. The long tail shortens through internal absorption and the gills are also absorbed or drop off. The lungs then appear, and for a time the young creatures are fully amphibious, breathing water through their gills and extracting the free oxygen from it, and also taking in air through the lungs; but soon the small frogs or toads take to the land and breathe air only (see Fig. 447). In those forms that remain permanently in the water the transformation is not so great, and some of them resemble fishes in bodily form throughout life, among these being the so-called hellbenders and mud-puppies common to the rivers of the Ohio and Mississippi valleys (see Pl. 27, Fig. 1).

Respiration. — All Amphibia in their youth are provided with two or three pairs of external gills or internal ones with external gill-clefts, soft feathery outgrowths situated at the back part of the head and rich in blood-vessels (see Pl. 27, Figs. 1–3). Such gills are also present in the lung-fishes, and in the sirens and mud-puppies they may persist throughout life, though this condition is rather exceptional. In the salamanders of the land, and in all of the tailless Amphibia (frogs, etc.), the gills disappear and adult respiration is carried on wholly by lungs, as in the higher vertebrates. While the gills are present, the air passages to the lungs through the nose do not open into the mouth, but assume this position as soon as the gills vanish and the lungs become functional. The air is then taken in through the nasal openings and in the frogs is forced into the lungs in a swallowing manner. Many of the Amphibia can live a long time without food, and in the colder

Plate 27. — Amphibia. Living tailed Urodela (1–4) and Permian stegocephalians (5, 6). 1, mud-puppy; 2, 3, mud eel or siren; 4, *Amphiuma*, which has both gills and lungs. British Museum Guide Book, and after Williston. See Appendix B.

countries all the land forms hibernate through the winter in the mud at the bottom of streams and ponds, breathing during this time only through the skin.

Hearing. — In none of the fishes are there functional ears, though there are internal ones; in the amphibians, however, there are distinct organs of hearing. These are best seen in the frogs, where the tympanic membrane of the ear-drum is a more or less large, circular disc embedded in the outer skin on the sides of the head. The cavity behind the disc, or drum, connects with the back part of the mouth by a tube known as the Eustachian tube, which is also present in all of the higher vertebrates.

Classification. — The living forms are divided into two subclasses on the basis of their body form: when tailless in the adult stage, they are called *Anura* (without a tail, see Fig. 447), while the primitive forms retaining the tail are called *Urodela* (having a distinct tail, see Pl. 27).

The Anura include the frogs and toads so commonly known. They always have four legs, the hind pair of which are long and powerful, and the adults are without external gills or gill-clefts. They are almost cosmopolitan, occurring in all countries except the cold polar regions. This subclass is of comparatively modern origin and but a single fossil form is known in the Comanchian, though in the Tertiary strata they occur far more frequently. They are the most diversified of living Amphibia, and, as they are also the most specialized, are not of particular interest in Historical Geology.

The Urodela or tailed Amphibia are of far more significance in this connection, and even though fossil forms are not known older than the Comanchian, the subclass must have had its origin in the Paleozoic Stegocephalia, which will soon be described. The Urodela, now practically restricted to the temperate parts of the northern hemisphere, are amphibians which as adults (salamanders, tritons, sirens, mud-puppies and axolotls) are often strikingly fish-like in appearance (see Pl. 27, Fig. 1). In the mud-puppies and axolotls there is an unpaired fin on the dorsal side, continuing around the diphycercal tail and along the posterior part of the ventral side, as in the lung-fishes. However, this fin does not have skeletal or bony rays, as in the fishes. Even though the Urodela are fish-like in appearance, they are readily distinguished by the fact that their paired appendages are not fins but fully developed legs, though small and weak, with all of the essential skeletal characteristics of the limbs of the higher vertebrates (study Pl. 27, Figs. 1–4). As a rule, there are two pairs of these

limbs, the front or pectoral, and the hind or pelvic. In some forms, however, only the anterior pair is present, the posterior one having been lost, and in a few species all of the limbs are absent, these latter being the burrowing, worm-like Cæcilians of tropical lands. The number of toes on each foot varies between five, the usual number, and two. Some forms, like the land salamanders, when matured may live wholly on the land and lose all trace of the gills, while others, such as the mud-puppies, remain in the water and preserve the gills throughout life. The Japanese and Chinese giant mud-puppy is the largest of all Urodela, attaining a length of 5 feet. One individual lived in captivity for over fifty years.

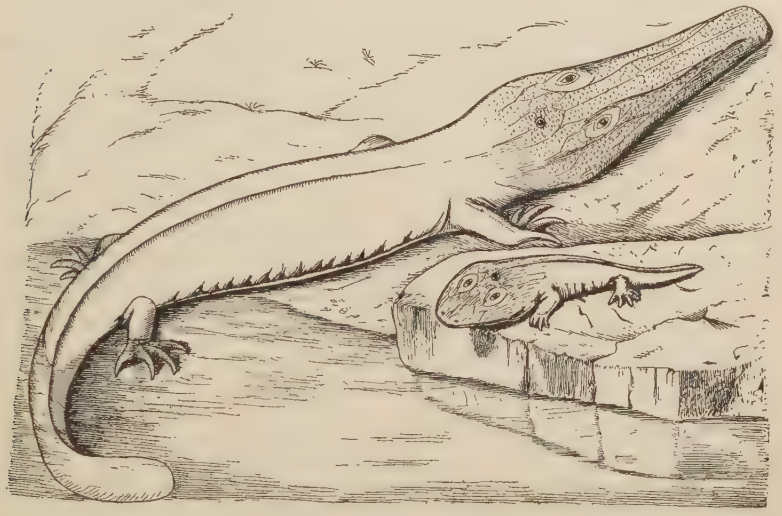


Fig. 448. — One of the larger Stegocephalia (*Archegosaurus*), 5 feet long, with a heavily armored skull; and a small tadpole-like form (*Branchiosaurus*), 6 inches long, whose entire ventral surface bears scales. Note the third or pineal eye. Lower Permian of Germany. From Museum Guide of the University of Tübingen.

Paleozoic Amphibia. — The first trace of an amphibian is a foot impression from the Upper Devonian (page 711 and Fig. 420), and skeletons are not known until Pennsylvanian times. These skeletons represent many kinds of salamanders or crocodile-like amphibians and are most common in America and Europe, ranging in size from less than an inch long to about 8 feet (Fig. 448, and Pl. 27, Figs. 5, 6). A tail was invariably present, and in most cases two pairs of limbs, though snake-like forms are also known (see Fig. 431). They are called *Stegocephalia*, a term which means covered

or mailed head and has reference to the fact that the upper surface of the skull was roofed over by more or less thick dermal bones which were often much sculptured. They are also known as the solid-skulled and armored Amphibia. The chest was likewise provided with dermal armor, consisting of three large sculptured plates which represented a part of the bones of the pectoral arch of the fishes and the shoulder girdle of higher vertebrates. In other forms the entire body was covered with small overlapping scales, those of the ventral side being the thickest, or the scales were on the ventral side alone. Nearly all living Amphibia, on the contrary, are naked and scales are but rarely present (Cæcilians). Many of the ancient forms have been called *Labyrinthodonts*, because in one group the dentine of the large and conical teeth was much folded in labyrinthine undulations.

The whole stock vanished at the close of Triassic time, but it was out of the Stegocephalia that the reptiles developed, and it is becoming increasingly difficult to distinguish the late Paleozoic reptiles from their stegocephalian ancestors. In other words, evidence is rapidly accumulating to show how this lower class of animals has changed into the higher reptiles, and that these changes had to do with their habitat, since the water-addicted Stegocephalia gave rise to forms that became completely adapted to the dry land. These later animals laid their eggs on the land to develop in the warmth of the sun, as do most of the living reptiles; hence the amphibian type of egg had to be modified into the reptilian type (see page 806).

Appearance and Habitat of Stegocephalia. — There are many kinds of stegocephalians known. Some were small and active, with well-developed walking legs and relatively short tails; some were active swimmers, with long tails; others of medium size were thick-set and sluggish in habit, like the crocodiles (Fig. 448); while a few had the appearance of being gigantic, almost legless, tadpoles wriggling about in the water. Their heads were usually broad and flat, with very wide mouths almost the full width of the skull, as in frogs and salamanders; but in some forms the heads were more or less elongated and even pointed, as in crocodiles. The heads of the latter, however, are also broad in the young stages, so that the broad head must be the primitive type. Of the former kind, *Eryops* of the Permian of Texas had a head 2 feet long and 18 inches wide and resembled a huge tadpole with a wide flat head, no neck, a thick heavy body, short legs, and a heavy flattened tail (see *Branchiosaurus*, Fig. 448). As Huxley has said, they

" pottered with much belly and little leg, like Falstaff in his old age, among the coal-forests."

The Stegocephalia lived not only in fresh waters, but, unlike their living descendants, also in brackish ones, and it is thought that some of them may even have lived along the beaches of the Triassic seas. Certain of the small, active types are found in hollow logs of the Pennsylvanian of Nova Scotia, and as thirteen skeletons have been discovered in association with land snails and myriapods, it is thought that they dwelt in trees and died in the places where found. Probably the great majority of Stegocephalia were carnivorous and fed on shell-fish, worms, and other water invertebrates, but more particularly on fishes, reptiles, and small members of their own tribe.

The Third Eye of Stegocephalia. — In all well-preserved stegocephalian skulls the armor or roof bones and those of the true skull were pierced not only by the large lateral orbits in which the paired eyes were situated and by the pair of anterior nasal openings, but also by a single small orifice through the bone over the brain (see Fig. 448). This aperture is of great interest, for in it was situated a third eye known as the *pineal eye.* Such an opening is also found in many fossil and some living reptiles, and while the organ it contains can hardly be regarded as acting like a true eye in living reptiles, its great significance lies in the fact that it is a vestigial organ whose ancestry can be traced back at least to Pennsylvanian time. The rudiments of this eye are present in the brain of all living vertebrates, including man.

In the living New Zealand lizard known as *Sphenodon,* the pineal body shows distinct traces of a retina — the latter being the innermost layer connected with the optic nerve which covers the posterior part of the eyeball — and is the vestige of either a pair of eyes fused into one, or of an unpaired median eye which looked upward. Its origin seems to have been in the lancelets, in which there is but a single median eye.

Sclerotic Ring. — In the cavities of the lateral or true eyes is often preserved a ring of small bones known as the sclerotic bones, which acted like an iris diaphragm for opening or closing the aperture that let the light in upon the retina.

Lower Jaw of Stegocephalia. — The lower jaw in almost all stegocephalians extended the full length of the skull and in consequence the gape of the mouth was very wide. Each half jaw, or ramus, was composed of at least three main pieces, one of which (dentale) bore numerous conical and generally striated teeth arranged in a single series and increasing in size from the front toward the back of the jaws. In some forms there were one or two large, curved, holding teeth in the front of the jaw on each side of the joint (or symphysis) connecting the two rami.

Limbs of Stegocephalia. — In the great majority of Stegocephalia the limbs were well developed but short and stumpy (see Fig. 448 and Pl. 27, Figs. 5, 6). The bones of the front legs were like those of living salamanders in number, form, and disposition, and the hands were provided with four, or rarely five, usually short fingers. The hind limbs were nearly always longer and heavier, and bore five toes, of which either the second or third was the longest. However, it should be noted that a number of stegocephalians are known in the Middle Pennsylvanian of Ohio with snake-like bodies completely devoid of legs and of body armor.

Stegocephalia of the Coal Marshes. — In the Lower Pennsylvanian at Linton, Ohio, underneath "coal No. 6," here a cannel coal, there have been found sixteen species of fishes and thirty-four of stegocephalians. There are a few lizard-like forms up to a foot long, still others with weak limbs, the posterior pair being absent, and ranging in size from 3 to 10 inches, while the most abundant are the snake-like stegocephalians without body scales and permanent gills, attaining to lengths of 4 feet (see Fig. 431). Associated with these are a few land plants, but there is not a trace of a marine animal.

Reptilia, Living and Fossil

In all of the vertebrates so far studied — fishes and amphibians — we have seen that their habitat is either wholly in the water, or that at the very least the small eggs are there laid and fertilized externally, and that the young are also born and spend the days of their youth in this element. All of the higher vertebrates remove themselves more and more from this habitat and none are developed in it directly from the egg. In other words, the reptiles, as a rule, are oviparous, laying *large* eggs like those of birds and provided with a more or less great quantity of food (yolk), and these eggs are fertilized internally by the males before they are laid by the females upon the land, where they hatch under the warmth of the sun. This is the most important and fundamental difference between the lower vertebrates, the fishes and amphibians on the one hand, and the higher vertebrates, the reptiles, birds, and mammals, on the other.

Living Reptiles. — All of the living animals known as turtles and tortoises, lizards and snakes, alligators and crocodiles, and the extinct types, the giant dinosaurs of Mesozoic time and the flying reptiles called pterodactyls, belong to the class Reptilia. The word *reptile* means *creeping* or *crawling* and has reference to an animal that goes on its belly like the snake, or moves with difficulty on short sprawling legs, like the alligator. There are, however, many reptiles that are in no sense creeping and crawling animals,

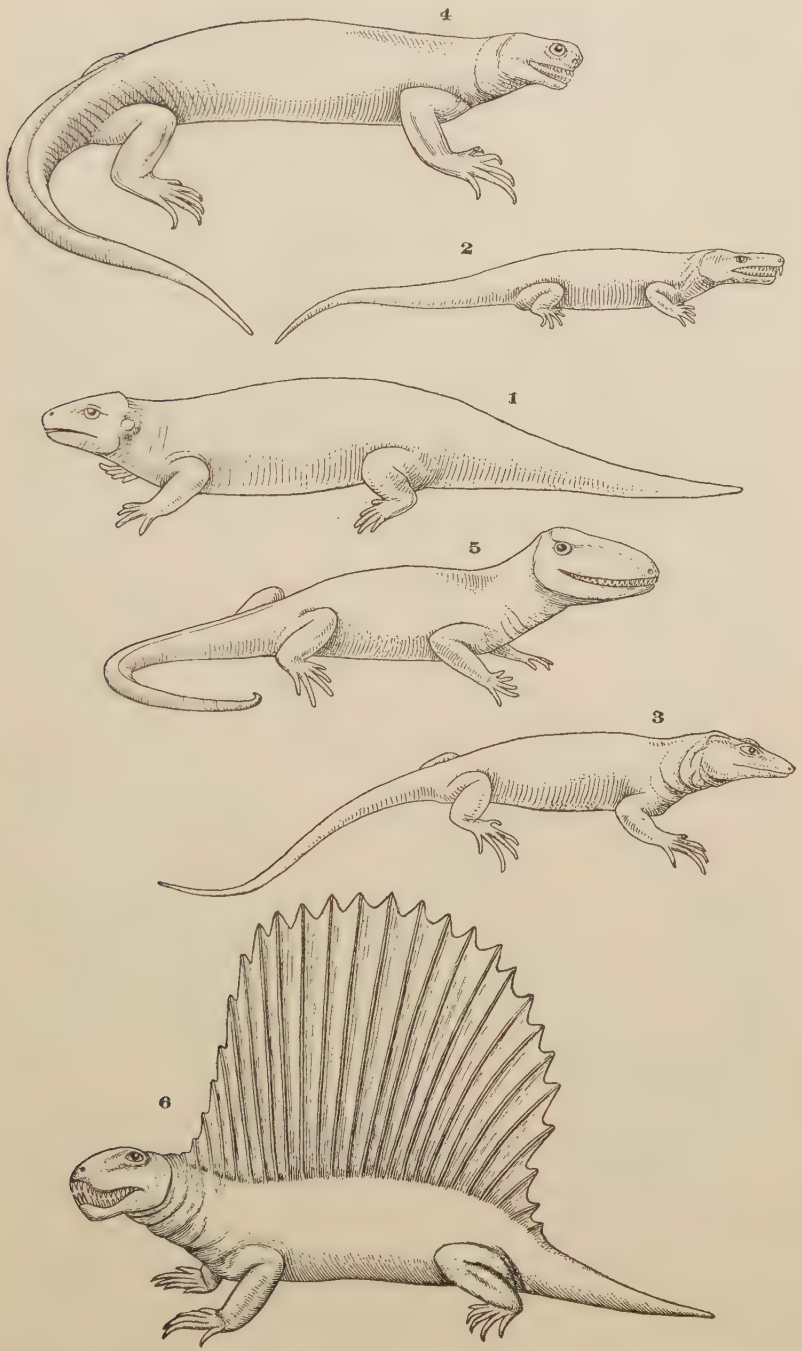


Plate 28. — Permian reptiles from Texas and New Mexico. After Williston. 1, 2, cotylosaurs; 3–6, pelycosaurs. See Appendix B.

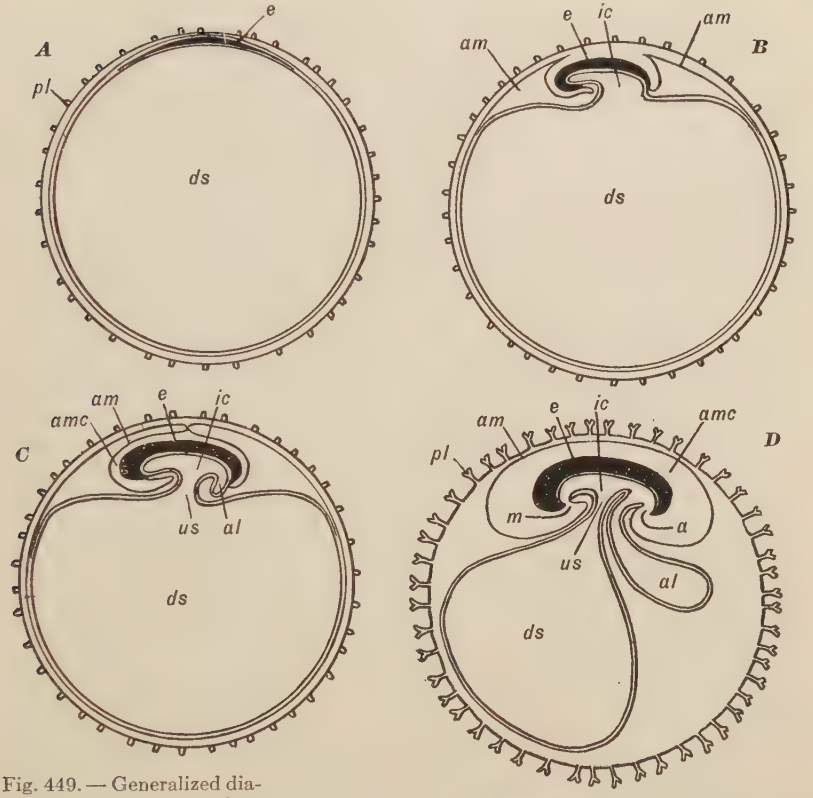
as, for instance, many of the fleet-footed lizards, the dinosaurs with their pillar-like legs, and the winged pterodactyls.

All living reptiles are cold-blooded animals like the fishes and amphibians, and their skin is never soft, but always more or less hardened by horny or bony material that occurs more often as scales than as armor plate. Even though many reptiles spend a large part of the time in the water, they are essentially land animals, as they are born on the land and breathe exclusively through lungs. Each animal has a pair of lungs, but in the elongated snakes the left lung is rudimentary and almost lost. In the snakes and in some lizards, legs are either wholly absent or mere vestiges buried in the flesh, and in such reptiles locomotion takes place by means of a wriggling movement either over the ground or through the water. Wherever legs are present, the fingers and toes have claws, a feature that is very rare among Amphibia.

In many of the reptiles eyelids are present, and in most lizards and fossil reptiles the pineal eye is well developed. The organs of smell and hearing are also well developed, but in the reptiles the vibrating, or tympanic, membrane of the ear-drum is no longer external, as in the frogs, but lies in a depression. With the exception of the turtles, nearly all reptiles have teeth; in living forms these are usually pointed and often recurved to serve for the holding of their animal prey. In many fossil forms, however, the teeth were adapted for cutting and more rarely for the mastication of food. In snakes and some lizards the tongue is slender and bifurcated and is protruded in a darting manner. In other reptiles the tongue is flat and immovable, as in crocodiles, being then attached to the floor of the mouth.

Development of Reptiles. — In some living lizards and snakes, and rarely among extinct forms, the females are viviparous, that is, they give birth to fully formed, living young. The great majority of reptiles, however, are oviparous. The eggs resemble those of birds, but are, as a rule, rounder and have a tough, parchment-like, porous covering, or in some cases a calcareous shell. As these eggs are very different in their development from those of fishes and amphibians, they need to be described in more detail.

Since the eggs of reptiles develop on the dry land they must naturally be very different in internal structure from those that hatch in the water. In the latter the embryos have functional gills for use in the water, but in the reptiles a wholly different organ was developed to provide the growing young with the necessary oxygen. Reptile eggs are large and contain a great deal of



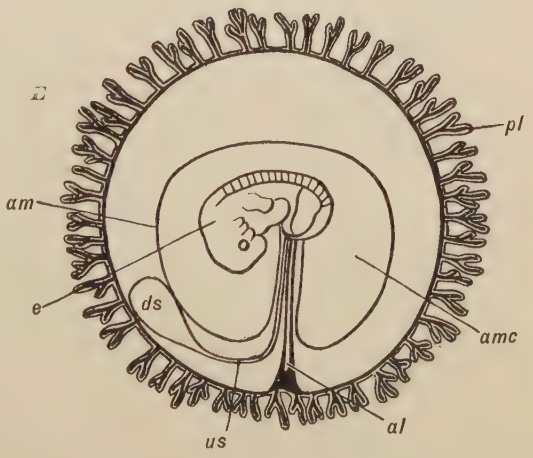


Fig. 449. — Generalized diagrams of a growing mammal egg sectioned to illustrate the fœtal organs in birds, reptiles, and mammals (Amniota). *A*, ovum with embryo just beginning to develop; *B*, somewhat older stage in section, with earliest stage of the forming amnion (*am*); *C*, ovum with amnion closing, and allantois (*al*) appearing; *D*, embryo with mouth (*m*) and anus (*a*); *E*, later growth, with fœtus more fully developed.

a, anus; *al*, allantois; *am*, amnion; *amc*, amniotic cavity; *ds*, cavity of embryonic vesicle, later the yolk sac; *e*, embryo; *ic*, intestinal cavity; *m*, mouth; *pl*, placenta, an organ found only in mammals, formed of the walls of the uterus and embryonal membrane; both are abundantly supplied with blood-vessels, and while there is no direct continuity in the two blood streams, nutrient materials and respiratory gases are exchanged by osmosis; *us*, umbilical stalk. After Kölliker.

yolk, on which the embryo lives and grows. At one pole of the egg lies the fertilized germinal vesicle which develops into the embryo (Fig. 449 *A*). During its earliest growth there is formed at either end of the elongate embryo a two-layered, crescent-shaped fold, called the *amniotic fold*, which arches over the embryo and finally unites to cover it with a protective hood. This latter is the *amnion*, and between it and the embryo there is a shallow cavity containing a watery *amniotic fluid*, bathing and protecting the outer surface of the embryo (Fig. 449 *B*). As the amnion occurs only in the eggs of reptiles, birds, and mammals, these groups are known collectively as the *Amniota*, and the fishes and amphibia, which lack it, are called *Anamnia*, meaning *without the amnion*.

While the amnion is being formed a sac grows out from the hinder end of the embryo, more specifically from the embryonic intestine. This sac, which is of the greatest importance to the animal, is never seen in fishes and amphibians, and is called the *allantois* (Fig. 449 *C*, *D*). It rapidly insinuates itself between the two sides of the amnion, eventually surrounding both embryo and yolk sac. This allantoic sac provides the embryo with the necessary oxygen, passing this and other gases through the porous shell. Finally the embryo breaks through the shell and begins to use its lungs, and the young reptile leads a free life (see Fig. 449 *A*–*E*).

Divisions of the Class Reptilia. — Reptiles are now divided into ten orders, but as most of these originated in the Mesozoic — the Age of Reptiles — we need concern ourselves at this time with the Paleozoic forms only. These are the Theromorpha or mammal-like reptiles.

Paleozoic Reptilia. — It seems probable that the Reptilia arose even earlier than earliest Pennsylvanian time, for in the latter part of this period occurred not only true reptiles but also highly specialized forms. In the Pennsylvanian and older Permian of Texas, Oklahoma, and New Mexico are found many different kinds of primitive Amphibia, and associated with them is even a greater variety of primitive Reptilia, animals that attained a maximum length of 7 feet (see Pl. 28). Their isolated and scattered bones and not infrequently complete skeletons occur in red clays that are devoid of the remains of all marine animals, such strata being regarded as the deposits of a delta or a very wide river valley under an arid climate but completely removed from the influx of the salt water of the sea. In the Wichita region of Texas, Williston has discovered two graveyards replete with entire skeletons, some

of which are 4 feet long, resting in a natural position and piled upon one another to a depth of 2 feet. The creatures had probably died quietly in a stagnant pool of water that dried out annually, causing successive generations of the reptiles to be heaped one upon the other in layers. Even to-day in the same region there are small perennial rivers in wide valleys, and here and there in the permanent pools live fishes, such as catfish and carp, along with frogs and mud-puppies. The modern occurrences suggest the probable conditions under which the late Paleozoic amphibians and reptiles existed.

Most of these late Paleozoic reptiles were plump, sluggish, more or less sprawling animals, basking often on the land in the hot sun, and swimming mainly by the aid of their tails. In many ways they still resembled the stegocephalians, their ancestors, but had a marked tendency toward a reduction in the size of skull and toward loss of body armor. In all the forms the feet terminated in five fingers or toes. Few appear to have been swift of foot, and some bore a curious, very high, dorsal, median crest (Pelycosauria, Pl. 28, Fig. 6). Most of the late Paleozoic forms were fierce looking animals because of their large, recurved, holding teeth, and all of the American representatives seem to have been carnivorous in habit, feeding on armored fishes, armored amphibians, and other reptiles. Others had crushing teeth, indicating a diet of shell-fish and crustaceans.

Cotylosauria were the solid-skulled reptiles (Pl. 28, Figs. 1, 2). They were the most primitive of the group and retained many of the ancestral stegocephalian characters; there was, however, at least one pair of temporal openings (pertaining to the temples of the head) and the teeth were not placed in grooves. The skull was armored with sculptured plates, the pineal eye was large, and a skin armor was sometimes present, all of these features being found in the Paleozoic amphibians. As a rule, the cotylosaurs were small to medium-sized animals, though one African form reached a length of more than 9 feet. In build they were low and stout, they were slow of movement and clumsy in walking, but since they had rather long tails, they swam well. All were carnivorous, though some fed partially on plants. Their geologic range was from late Pennsylvanian to late Triassic, and, while most of them lived in America and Europe, there were some species in South Africa.

Pelycosauria, sometimes called the "fin-backed lizards," were a highly specialized group of Theromorpha (Pl. 28, Figs. 3–6). They were more active and lizard-like than the cotylosaurs, with longer tails, which were not, however, used for swimming. Some were also plump and bore a more or less high dorsal bony crest or "fin," which must have given them a most bizarre appearance. Others, more slender, attained a length of 8 feet. All were fiercely carnivorous land animals, and in certain forms the teeth were enormous, in others somewhat flattened and bearing lateral serrations for the easier cutting of flesh. Pelycosaurs lived

from Upper Pennsylvanian to late Triassic times and were most abundant throughout all of North America, though they also inhabited Europe. None have been found in Africa.

Theriodontia were reptiles which lived only in South Africa during Permian and Triassic times and ranged in size from small forms to those as large as a

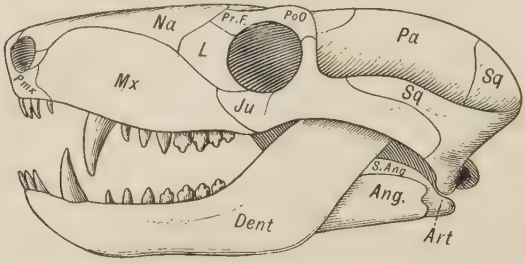


Fig. 450. — A theriodont reptile skull, about 4 inches long, from the Triassic of South Africa, showing primitive mammalian type of teeth. After Broom.

tiger. They are of great interest in Historical Geology as indicating the probable group of reptiles that gave rise to the lowest or egg-laying mammals. Their teeth were differentiated and localized, as in mammals, into incisors, canines, and molars (see Fig. 450).

CHAPTER XLV

THE BEGINNING OF MESOZOIC TIME: THE TRIASSIC PERIOD

Mesozoic Era

To the founders of Geology the Mesozoic rocks were known as the "Secondary" formations, situated above their Primary (Paleozoic and older eras) and beneath their Tertiary divisions. To them the Mesozoic was the middle or medieval time of the earth's history, and they therefore selected a name meaning *medieval life* to express that idea. It is now well known that the Mesozoic formations are far from holding the middle time of geologic history, but the term is perpetuated, though with an amended meaning.

Divisions of Mesozoic Time. — The Mesozoic era, though of very long duration, was only one half as long as the Paleozoic, or even less, but it was twice as long as the Tertiary. At first the era was divided into three periods — the Chalk or Cretaceous, the Oolite or Jurassic, and the New Red sandstone or Triassic; but now the tendency is to recognize four periods, by dividing the great chalk formations into a lower and an upper series, which in America are known respectively as Comanchian and Cretaceous. These four periods, on the basis of organic change, and because of the decided movement that gave rise to the Sierra Nevada Mountains, can be grouped naturally in America into two sub-eras, the Early Mesozoic (Triassic and Jurassic) and Late Mesozoic (Comanchian and Cretaceous).

Characteristic Life of Mesozoic Time. — Louis Agassiz long ago called the Mesozoic the *Age of Reptiles*, because those animals then dominated the world. The Mesozoic Reptilia were very diversified in form and adaptation — small to gigantic, sluggish to agile — but their mentality was always of a low order. Scott tells us: "They filled all the rôles now taken by birds and mammals; they covered the land with gigantic herbivorous and carnivorous forms, they swarmed in the sea, and, as literal dragons, they dominated the air."

Out of the reptiles early in the Triassic arose the small and insignificant reptilian and egg-laying mammals, and from another stock came the reptilian birds, with an abundance of teeth; both

stocks at the close of the Mesozoic era began to modernize into suckling mammals and toothless birds respectively. Among the Paleozoic amphibians, the stegocephalians vanished with the Triassic, and their only living remote descendants are the salamanders and the greatly modified frogs of Comanchian origin.

Of the dominant Paleozoic animals, the trilobites, sea-scorpions (eurypterids), blastids, tetracorals, and graptolites were gone, while the crinids, echinids, and brachiopods were greatly modified and the kinds were not only characteristic of the era, but more like those of the present. The bivalves and gastropods were undergoing great change in the Early Mesozoic, and the culmination of their evolution was attained in Late Mesozoic time. Oysters have been abundant since the Jurassic. The ammonids of the Permian gave rise to a wonderful evolution in the Triassic but were almost exterminated at the close of this period; another rapid evolution took place in the Jurassic, with the Comanchian they began to show decline, and at the close of the Cretaceous they had disappeared. Among the marine invertebrates none were more significant of Mesozoic time than the ammonids.

The floras had also undergone great changes, since all of the more significant spore-bearing plants of the Paleozoic were practically gone and the ancient ferns were changing into the modern stocks. The older seed-bearing plants had given rise to modern conifers and cycads, and the latter dominated the floras of Early Mesozoic time, which is often called the *Age of Cycads* (see Figs. 318, 458). With the Comanchian, the modern flowering plants and insects (beetles, flies, ants, bees, wasps) took their rise, and we may say, in fact, that much of the modern floral and insect world has been established since early in the Cretaceous.

Triassic Period in Europe

The Term Triassic. — In Germany at the opening of the last century, the three-fold stratigraphic nature of the Triassic was already well known, Germany and the Alps being the regions from which most of our knowledge of Triassic time has come. At the base occurs the variegated sandstone member (Bunter, 650–2000 feet) of fresh-water origin, which is overlain by a more or less thick shell limestone (Muschelkalk, 800–1100), made by an epeiric sea that spread northward into Germany from the mediterranean Tethys. This sea again vanished and local coal swamps appeared; then followed variegated continental deposits that are mostly of a red color, along with beds of gypsum and more rarely of salt (Keu-

per, 800–2000). This is the *Germanic phase* and to it Alberti in 1834 gave the name Triassic because of its three-fold development. In England there is no Muschelkalk and all of the Triassic is of continental origin; originally these deposits were known as the New Red sandstone.

In the Alps, and especially in the Tyrolian region, where the deposits are of marine origin, with a wonderful array of fossils, the Germanic classification cannot be applied. Here the Triassic is divided into four members, and as they are of normal marine sediments, this development is spoken of as the *Alpine* or *normal phase.* The latter has become the standard of correlation for the marine strata of this period, while the Germanic phase interprets the land conditions and the diastrophic movements.

Gümbel holds that the area in which was formed the Germanic phase of the Triassic was separated from that of the Alpine or normal marine development by a low mountain tract — the Vindelian mountains — that existed throughout the entire Mesozoic from the Riviera and Sardinia along the Bohemian-Bavarian boundary to the central plateau of France.

Triassic of North America

The Appalachian Revolution (see page 748) not only raised the eastern and southern border of North America into a mountainous tract, but extended the continent to an unknown distance into the Atlantic Ocean as well. Therefore the greater eastern half of the continent remained above the sea for a very long time, certainly to the end of the Jurassic. A further reason why the sea did not spread over this region lies in the fact that another period of elevation set in at the close of the Triassic — the Palisade Disturbance. Hence the geologic record is one of erosion, the making of land forms, and the accumulation of continental deposits in thick series. Along the Pacific border, however, there is a long marine sequence that can be divided in harmony with the European records, and these waters also spread their sediments over much of the entire Rocky Mountains area, but in the main as fresh-water red muds and sandstones. The Triassic of North America is therefore displayed under three different regional sedimentary and faunal phases: (1) Pacific coast normal marine, (2) Rocky Mountains fresh-water, and (3) Atlantic border intermontane continental deposits.

The physical conditions and the absence of the sea in eastern North America in Triassic time were also repeated in South America, most of Africa, and northern Europe and Asia. In other words, the revolution at the close of the Paleozoic

was decidedly positive and extended over the greater part of the earth, leaving most of the continents standing well above sea-level, while the main areas of oceanic overflow were the bordering lands of the Pacific and Tethys. During Middle Triassic time only did Tethys flow widely northward over Europe and lay down the well known epeiric limestones called the Muschelkalk. In nearly all the lands mentioned the climate was semiarid to arid.

Subdivisions of the American Triassic

Marine and continental phases of Europe				American Pacific	Rocky Mountains	American Atlantic	
Triassic	Upper	Bajuvarian / Tirolian	Keuperian	Hosselkus / Swearinger	Vast areas of red beds	Newark series	Brunswick / Lockatong / Stockton-Norristown
	Middle	Dinarian-Franconian		Pit			
	Lower	Scythian-Vosgian		Inyo-Aspen			

Newark Series

Appalachian Revolution. — The Appalachian Mountains, consisting of many ranges that were completed in Permian time, were even then undergoing reduction, and all of the products of erosion were being swept into the oceans. Seemingly the same conditions continued into the Triassic, for no one has yet found among the few fossils of this period in eastern America any that are indicative of the earliest epoch. The fishes, Eastman says, indicate early Upper Triassic, while the plants Stur regards as of the same time. In any event, the Triassic deposits of Nova Scotia (see Fig. 75, page 91) lie upon the nearly peneplained and truncated edges of Paleozoic formations ranging from the Ordovician to the Pennsylvanian. In Pennsylvania and New Jersey the Triassic lies on the planed edges of the Lower Paleozoic. From this evidence we see, further, that the folded structures of Permian time had suffered profoundly from erosion even by the beginning of Newark deposition.

Newark Sedimentation. — The term Newark is taken from Newark, New Jersey, and was proposed by Redfield for the red sandstones found upon the Piedmont Plateau (Fig. 451). Beginning with about Middle Triassic time, the several regions of Newark sedimentation — Nova Scotia, Connecticut, and New Jersey to North Carolina — began to fault along definite lines, and certain narrow but long areas began to subside as troughs, while the adjacent spaces stood firm as unmoved blocks (horsts), or actually rose. In this way the horsts were reëlevated from time to time into more or less high lands, and their eroded material was dragged by the rivers into the subsiding valleys. Such major fault lines

occur along the eastern side of the Connecticut valley and others are known in Maryland, New Jersey, Pennsylvania, and Nova Scotia. In this way the constantly rejuvenated highlands were subjected to quick erosion, and into the sinking valleys on the sides

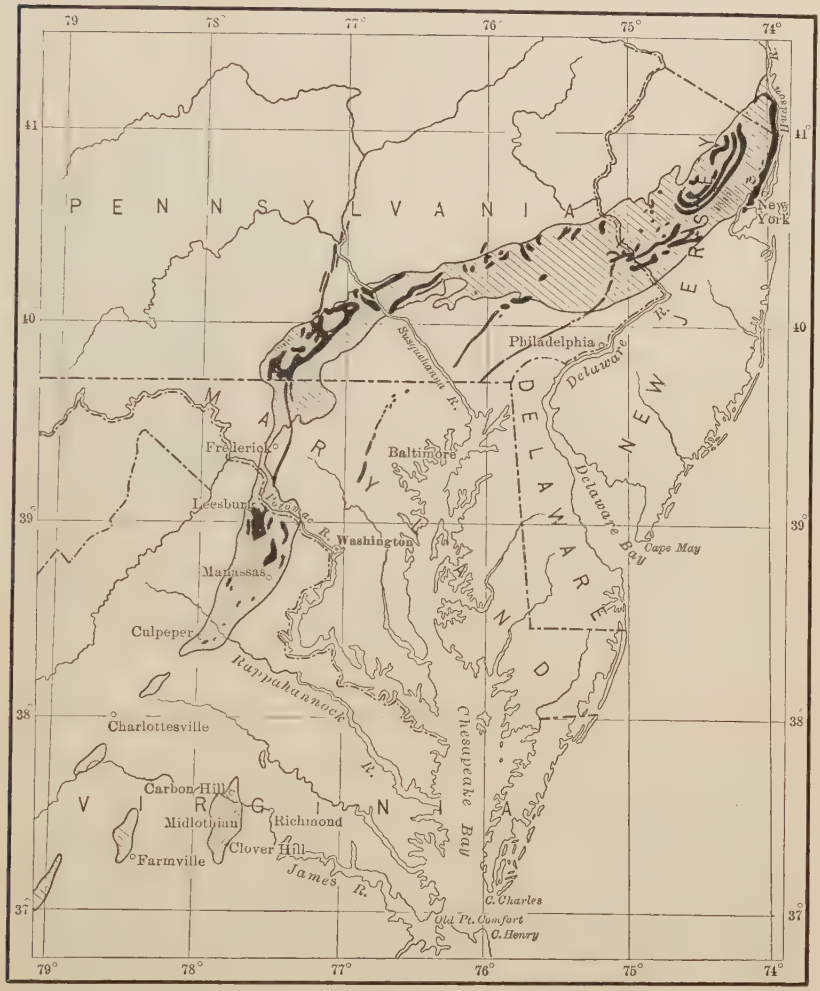


Fig. 451. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Atlantic States. U. S. Geol. Surv.

of the horsts the aggrading rivers brought down vast amounts of sediment, the present Triassic formations. Because of their subsidence the loading troughs also came to lie below the plane of erosion and so were preserved throughout subsequent time. In

the Connecticut valley there are from 10,000 to 13,000 feet of continental deposits (Fig. 452), in New Jersey and in southeastern Pennsylvania the maximum thickness is estimated at 20,000 feet. Southward these deposits thin rapidly, and around Richmond, Virginia, they are about 2500 feet thick, and in North Carolina 3000 feet (Fig. 451).

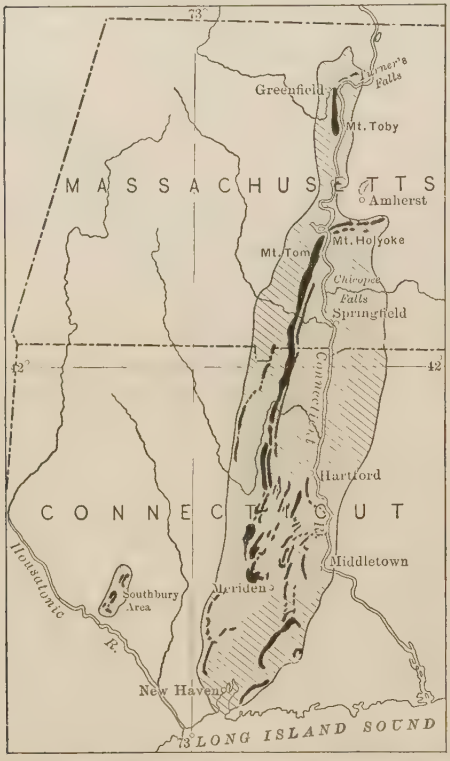


Fig. 452. — Triassic continental deposits (ruled areas) and igneous rocks (solid black) of the Connecticut valley. U. S. Geol. Surv.

The character of the formations and the geological structure of the Newark troughs are analogous to those which exist at the present time in the Great Valley of California and the Sierra Nevadas. There, uplift on the east and downsinking on the west during the later Tertiary have given rise to profound erosion of the uplifted side and transfer of sediment onto the sinking floor. A fault zone separates the Great Valley, the downsunken side of the block, from the Coast Range. The latter also contributes sediment to the valley, but the greater part comes from the crystalline rocks of the Sierras on the east. (Barrell.)

Igneous Material. — In all of the areas from Nova Scotia to North Carolina are found igneous rocks that in the lower strata occur as intruded sheets and dikes of trap (diabase) (Figs. 453, 455) and higher up are extruded sheets of basaltic lavas in thicknesses up to 900 feet (Figs. 451, 452). These are seen to best advantage along the Hudson River of New Jersey, where they make the well known Palisades, whose vertical walls of columnar rock exhibit the edge of a great intruded sheet of diabase. Although the remains of small volcanoes have been found in Connecticut there seem to have been no great ones at this time, and the molten material welled up repeatedly toward the close of Newark time through fissures situated near the great faults, and the lavas were either intruded into the sediments or for the most

part flowed widely throughout the valleys of sedimentation and away from the horsts and rising blocks. Undoubtedly the great subsidences of the sinking valleys fractured the earth's crust deeply enough to let the magmas escape.

Character of Sediments. — From northern Virginia to Nova Scotia the Newark rocks (3300 to 6500 feet thick) are prevailingly red in

Fig. 453. — Palisades of the Hudson River along the New Jersey shore. Note the columnar intrusive diabase above. Photograph by W. H. Rau.

color and consist almost throughout of conglomerates, sandstones, and shales. All of the material is poorly washed or assorted, and in most places is a heterogeneous mass of rock material with the greater part of the conglomerates and the coarser sandstones situated near the fault scarps whence they came. The great bulk of the material is from granitic rocks, showing that the higher lands lay to the east of what is now the Piedmont Plateau (the rolling land east of the Blue Ridge, see page 705), that is, eastern Appalachia, which is made up of Archeozoic and Proterozoic rocks.

Nowhere have the Newark strata yielded a single marine fossil, all of the recovered organisms being those of the land (plants and vertebrates) and of fresh waters (fishes, bivalves). Actual remains of plants and animals are always rare in red deposits, due to the complete oxidation of the sediments during deposition, and

Fig. 454. — Natural casts of rain imprints and dinosaur tracks on a fine-grained sandstone. Yale University Museum.

Fig. 455. — West Rock, New Haven, Conn. Above is the jointed and columnar intrusive trap or diabase, resting on the eastwardly dipping red Triassic sandstone.

the common organic evidence therefore consists of footprints or autographs made by quadrupedal and bipedal terrestrial reptiles (chiefly dinosaurs) (see Figs. 460, 461). The plants and fishes occur in dark to black shales which are evidently the mud deposits of lakes. The sediments themselves are much cross-bedded, abundantly sun-cracked, rain-pitted (Fig. 454), and rippled, with the feldspars undecomposed; they are the erosion material of a high land of crystalline rocks, deposited in a semiarid climate with hot summers and possibly cold winters. (Barrell.)

Connecticut Valley. — In the Connecticut valley the Triassic is readily divisible into three series because of a great medial zone of lava flows. The *upper series* embraces the many quarries about Longmeadow, Massachusetts, and Portland, Hartford, and Middletown, Connecticut, and consists of coarse sandstones, conglomerates and shales, about 3500 feet in thickness, with an abundance of reptilian tracks, chiefly dinosaurian. Very rarely, however, is a skeleton or even a bone of a reptile found, though Hitchcock and Lull have described ninety-eight different kinds of vertebrate tracks. The *middle series* has at the top the posterior lava (trap) sheet, 100 feet thick, beneath which are the posterior shales with land plants and ganoid fishes, attaining a thickness of 1200 feet; then come the main lava flows, 400 to 500 feet thick, followed by the anterior shales from 300 to 1000 feet thick, with plants, fishes, and tracks of dinosaurs; at the base is the anterior lava sheet, 200 to 250 feet thick. The *lower series* consists of coarse granitic sandstones, frequent conglomerates and some shales, and intrusive traps such as those of East and West Rocks at New Haven, with a united thickness of 5000 to 6500 feet. Fossils are very scarce in this lower series.

Fig. 456. — Giant broad-leaved Triassic fern, *Macrotæniopteris magnifolia*. U. S. Geol. Surv.

Coal Beds. — In the Triassic areas of Virginia and North Carolina there is much fine-grained, black, bituminous slate, with decidedly local bituminous coals, and rarely a zone of black-band iron-ore. The coal beds vary in thickness from a few feet to 13 and even 26 feet. Plants are common here, and of these eight are conifers, twenty-three cycads, six rushes, and thirty-five ferns. Among the latter occurs the broad-leaved giant fern (*Macrotæniopteris*, Fig. 456). Very rarely are seen amphibia,

reptiles, and reptilian mammals (*Dromatherium* and *Microconodon*, Fig. 462). These dark deposits with coal swamps, in which Lyell also reports many rushes that still stand vertically, show that the climate of the area of sedimentation was not always and everywhere semiarid, but that locally there were humid climates, with swamps having an abundance of cycads, ferns, and rushes.

Palisade Disturbance. — At the close of the deposition of the Newark series, deformation again set in, and apparently on a considerable scale, from Nova Scotia to South Carolina. Everywhere this new area of deformation lay east of the Appalachian foldings, whose trends the Palisade mountains nevertheless closely followed. The former mountains had been folded and overthrust, due to shortening of the earth's crust, but now the surface was torn apart, resulting in numberless fractures and faults (tensional) of varying magnitude, and moving the strata in each basin into a series of monoclinal blocks, that is, all tilted in the same direction. As a result there were formed chains of block mountains, the Palisade mountains of Dana, probably comparable in height to the Sierra Nevadas of to-day (Fig. 453).

The Palisade mountain system comprised eight to ten independent ranges. They occurred at intervals over a region 1000 miles long, extending from Nova Scotia southwestward to the northern limit of South Carolina. The ranges were from 10 miles to about 350 miles in length and their general course was closely parallel to that of the Appalachian Mountains. The Connecticut River range was 120 miles long, and the Palisade range, extending from southern New York, on the Hudson, into Virginia, was 350 miles long.

The dip of the beds is, with rare exceptions, monoclinal, and mostly between 5° and 25° in angle. In the Connecticut valley, it is *eastward*, in the Palisade belt, *westward*. In two North Carolina belts, the eastern has eastward dip, and the western, westward (Pl. 29). (Dana.)

Marine Triassic of Western North America

Triassic of the Pacific Border in the United States. — Our knowledge of the West Coast or Pacific Triassic is good only for the states of California, Nevada, Idaho, and Oregon, and it is due mainly to the work of Professor J. Perrin Smith. He states that the development of the western Triassic is unusually complete, and in thickness compares favorably with that of any other region of marine sedimentation. The deposits are usually calcareous and fairly thick (about 4000 feet), facts which are in keeping with the view that, as no mountain ranges were developed along the Pacific border at the time of the Appalachian Revolution, there was no high land present to furnish the adjacent seas with much sand and mud (see Pl. 29).

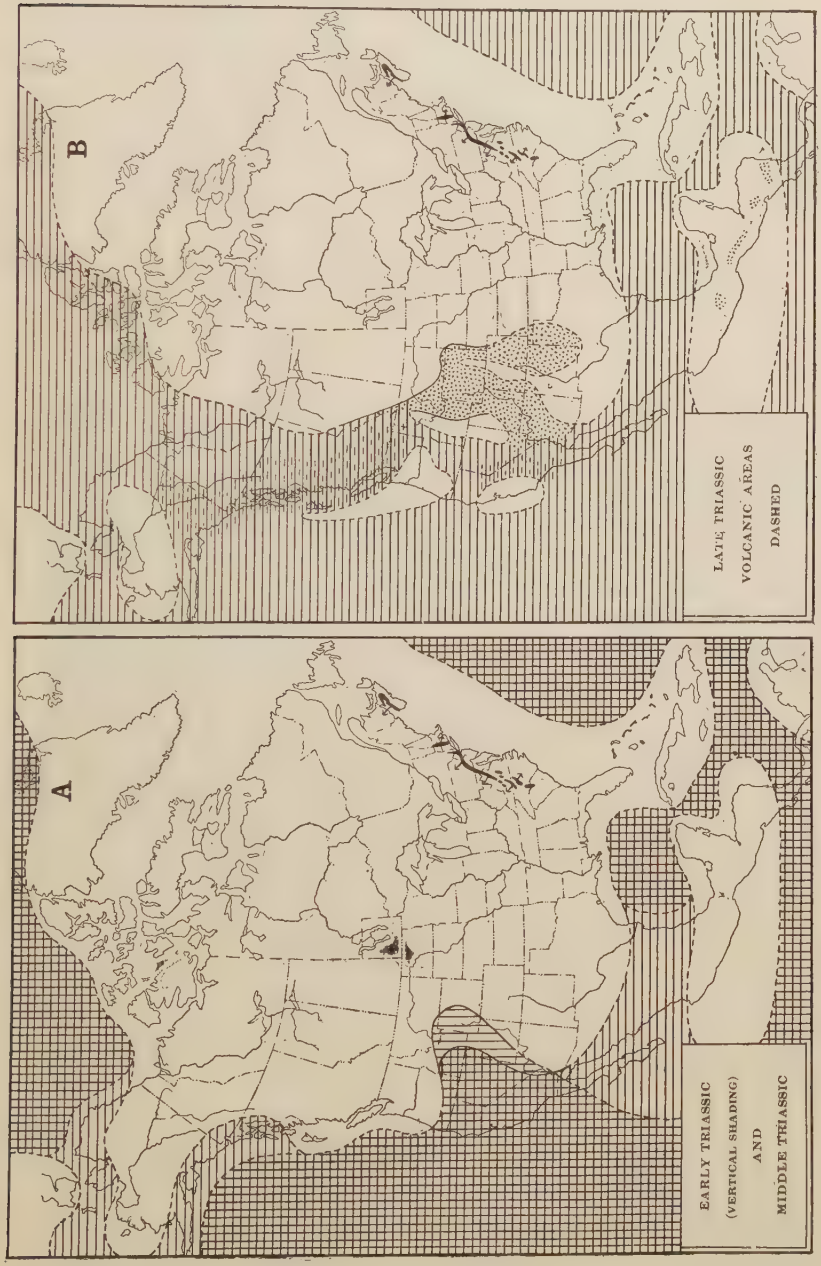


Plate 29. — Triassic paleogeography. Eastern continental strata in black; western, dotted.

The Lower Triassic is about 800 feet thick, the Middle division has about 1000 feet, and the Upper is the thickest, with about 2000 feet. The Middle Triassic faunas are as yet the only ones fully made known, but an estimate based on them indicates that the whole Triassic of this region will yield more than five hundred species, and of these over 70 per cent are ammonids (about ninety genera). All of this, moreover, was true Mesozoic life, for at best there were but few Paleozoic genera then present. The corals (Hexacoralla) made reefs in the Upper Triassic that are known to extend from California into Alaska (60° north latitude), indicating that the waters were warm.

Triassic of British Columbia and Alaska. — Along the Pacific border of British Columbia, from Vancouver north to the Queen Charlotte Islands, the Triassic increases to very great thicknesses (Nicola formation), attaining, according to Dawson, to 13,000 feet. The significant feature, however, is not so much the thickness as the fact that more than nine tenths of the rocks are of volcanic origin. The material is that of submarine eruptions — effusive diabases and trachytes, agglomerates, breccias, and tuffs. With these are interbedded zones of marine sediments, argillites and quartzites, that are thin or even absent to the east, while on Vancouver one such horizon reaches a thickness of 2500 feet.

The Pacific overlap had its widest distribution in the Upper Triassic, for its deposits occur at various points along the western border of North America, and widely over Alaska and Arctic America, with an isolated occurrence in northern Mexico (Zacatecas). These normal marine waters during early Triassic time spread across California and Oregon into Idaho and Utah, and possibly even into central Wyoming. In Middle Triassic time the sea withdrew more and more westerly, so that the Upper Triassic of the Rocky Mountains is all of continental origin.

The marine faunas of the Pacific Triassic were largely indigenous, with decided migrations at times from Asia and the Arctic Ocean by way of the northern Pacific shelf-sea route, and at other times from the western mediterranean (Tethys), seemingly by way of the north shore of Gondwana (see pages 466, 761), and across northern Mexico into the great Californian sea (Walcott, 1894). There appear to have been at least six of these faunal waves, the Asiatic migrations alternating with those of the mediterranean (Smith).

Volcanoes of the West Coast. — The submarine or shelf-sea volcanoes above referred to began their eruptions in Middle Triassic time and seem to have been most active in the early Upper Triassic, when they extended from southern California into Alaska (see Pl. 29). Locally, however, these volcanoes remained active throughout the closing epoch of the Triassic. Near Mt. St. Elias there are about 4000 feet of basalts, followed by the same thickness of Upper

Triassic limestone (Chitistone) and 2500 feet of dark shales. As the Jurassic here rests with a marked unconformity upon these older rocks, it is evident that the Triassic closed with deformation and active erosion throughout the Alaskan region.

About the same time that the volcanoes were active along the Pacific border of North America, much lava flowed out through fissures in the eastern part of this continent (Newark series), as previously stated. Similar lava flows occurred in Argentina and Brazil, but on a more extensive scale, and up to a thickness of 1500 feet (Woodworth). Active volcanoes also existed in New Zealand.

Triassic Red Beds of the Cordilleran Region. — Throughout the Rocky Mountains region, from the Canadian border south into western Texas, and in northern New Mexico and Arizona, occurs

Fig. 457. — Cross-bedded Triassic sandstone (De Chelly), Monument Uplift, Arizona. Photograph by H. E. Gregory.

a series of red or variegated sandy shales and cross-bedded sandstones (Fig. 457), with zones of gypsum sometimes 40 feet thick, that lie over the eroded surfaces of the older formations, and commonly on similar red beds of Permian or Pennsylvanian age. Because of the scarcity of fossils in these red beds, the two series are not yet clearly distinguished in all places. In general, however, it may be said that in the eastern and central portions of the Rocky Mountains area these Triassic formations are thinnest, averaging from 200 to 400 feet thick, and increasing in depth westward to 1000 feet and more. They are all of continental origin.

The fossils of these Upper Triassic red beds are scanty indeed,

but none are of marine origin. Here and there fresh-water bivalves occur (*Unio*) and in many places in the upper portion are thin zones with broken bones, known as bone conglomerates. These bones are in part remains of amphibia (Stegocephalia), but mainly of reptiles of the ancient crocodile type (*Mystriosuchus*, Fig. 458) and of dinosaurs. Characteristic plant remains are almost absent, but nearly everywhere occurs drifted wood that is now agatized; in the Petrified Forest of Arizona, near Flagstaff, this is exceedingly common, and great logs may be seen 120 feet long and with diameters of 8 feet, although the common thickness is from 2 to 4 feet (Fig. 459).

Fig. 458. — Restoration of the Upper Triassic crocodile-like reptile *Mystriosuchus*. The plants are rushes and cycads (upper left-hand corner). After Williston, from his *Water Reptiles*.

Chitistone Disturbance of Alaska. — In Alaska along the Pacific border, from at least Mt. St. Elias to the middle of the Aleutian Peninsula, the Triassic and older formations were thrown into a folded series of mountains at the close of the Triassic. In the lands bordering on the Cook Inlet country, the Triassic strata are, in places, also closely folded and crumpled. Moreover, soon after their folding, they were intruded by felsitic (dense not glassy) igneous rocks, and they are overlain unconformably by Lower Jurassic formations that are far less deformed. In the Mt. St. Elias region the folding seems

to have been less intensive, though here the erosion cycle lasted until about Upper Jurassic time, when the sea came in over the beveled edges of a great thickness of Triassic sedimentaries and volcanics. It seems very probable that the Chitistone mountains extended across the peninsula of Alaska far southward into British Columbia. Finally, a marked break in sedimentation, due either to non-deposition or to erosion of Triassic formations, separates the Jurassic of California from the Triassic, a condition also common to the entire Pacific Coast region. To emphasize this marked diastrophism, the period of orogenic mountain making is here named the *Chitistone Disturbance*, after the thick limestone of the same name so well developed in southeastern Alaska.

Fig. 459. — Three silicified logs of Triassic age in Fossil Forest Park, Arizona. U. S. National Museum.

Life of the Triassic

In the previous pages some mention has been made of the Triassic life of the various American regions, but in this place it is proposed to point out the essentials of the Triassic floras and faunas.

Land Plants. — The Triassic floras are small, as not more than 400 forms are known in all the world, and of these 150 occur in America, with the best representation in Virginia. Practically all the known floras are of Upper Triassic time. Of the Paleozoic genera, nearly all had disappeared. The Triassic flora consisted

essentially of rushes, many of them large; ferns, including tree ferns; and cycads and conifers in many genera (see Figs. 456, 458). The evergreen trees were dominant in the forests and were as tall as the conifer woods of to-day (Fig. 459). In the swamps the rushes made dense brakes like the canes at present, and in general we may say that the vegetation of the Triassic was monotonous. While it was not a luxuriant vegetation, the plants were not dwarfed, as might be expected from the general prevalence of warm semi-arid to desert climates whose existence at that time is proved by the wide-spread red beds and desert sands. Further, there were no marked seasonal changes, as the trees were devoid of annual growth rings, and it is held by botanists that the climate was warm and subtropical. (Knowlton.)

Fig. 460. — Slab of Triassic sandstone, 6 by 3.5 feet, pitted by rain. A large dinosaur (*Steropoides diversus*) walked over the muddy ground before the storm, and a much smaller one (*Argoides minimus*) afterward. Yale University Museum.

Insects. — Our knowledge of Triassic insects is almost a blank, for less than thirty species are known, and of these about two thirds are beetles, a group of animals that arose in this period.

Fresh-water Faunas. — In the Triassic the fresh-water deposits contain *bivalve shells*, and in a broad way we may say that these were not very unlike those of the rivers and lakes of to-day. Of course, the species, and in most cases even the genera, were not the same, but nevertheless the pearl shells (Unios) were abundant. Fresh-water snails, although they arose in the Pennsylvanian, were still rare. The *lung-fishes* were greatly reduced in number, and

the dominant forms were the *ganoids*, with the bony fishes advancing toward our present types.

Land Animals. — The vertebrates of the land were now very varied and of great interest, exhibiting much structural and adaptive progression over their late Paleozoic ancestors. Among the amphibia the *stegocephalians* attained their culmination in number, variety, and size. Progression was, however, especially marked among the Reptilia as a class, and specifically among the active dinosaurs (see Pl. 31). Scott tells us that almost all of the twenty-five orders of Mesozoic reptiles were already represented in the Triassic, though often by comparatively small and rare forms. Their footprints are known in eastern North America in great variety (Figs. 460, 461), but good skeletons are exceedingly rare. In Europe,

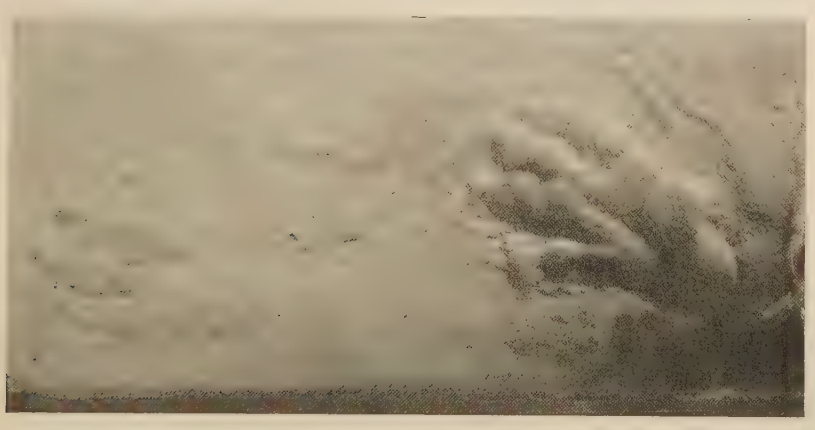


Fig. 461. — Tracks of the largest known Triassic dinosaur (*Otozoum moodii*). Slab 4.5 by 2 feet. Yale University Museum.

on the other hand, their skeletons are more common, and, so far as known, the animals were of the same kinds as those of America. From this and other evidence it appears that the great northern continent Eria (Fig. 434) was still intact and was the land across which the plants and animals of Triassic time readily migrated to and fro. *Crocodile-like reptiles* of the sprawling type (*Mystriosuchus*, Fig. 458) and other active forms (*Aëtosaurus*, Pl. 31, Fig. 9) were common. Genuine *turtles* occur in the Triassic rocks, showing that the group originated in the Permian. No lizards, snakes, or birds are as yet known in rocks of this era.

The *dinosaurs*, however, were the lords of the land, and they were present in great variety and in great size; in fact, some, known by

their footprints only, must have been larger than elephants (Fig. 461). In the Upper Triassic they had become adapted to all the land habitats. Some were herbivorous, others carnivorous; some walked on all fours; others walked occasionally or habitually on two legs, after the manner of birds. The best known American form is the carnivore *Anchisaurus* (Pl. 31, Fig. 6).

Archaic or Reptilian Mammals. — Of greatest interest is the rare occurrence in the Triassic of Virginia (two lower jaws, Fig. 462) and Europe (isolated teeth) of diminutive reptilian mammals. Mammals are the most highly organized animals, but these, their earliest known representatives, were very small and very primitive,

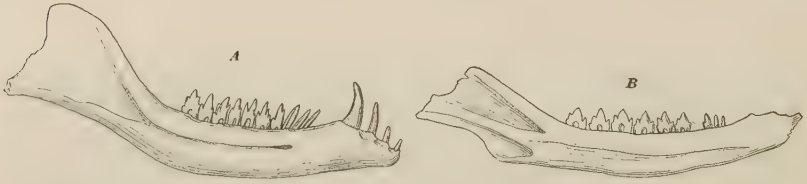


Fig. 462. — Lower jaws of reptilian mammals from the Triassic of Virginia. *A*, *Dromatherium*, × 2; *B*, *Microconodon*, × 3. After H. F. Osborn.

giving little promise of being the future conquerors of the world (Scott). They probably had their rise in the mammal-like reptiles known as the Theriodonta (Fig. 450, the name meaning beast-tooth, and having reference to the resemblance between their teeth and those of carnivorous mammals) which were common in Africa and Europe during the Triassic. The first stock of mammals to arise were the Multituberculata (Fig. 484), so named because the teeth have coned or tuberculated surfaces; these were reptilian, probably egg-laying mammals. Of this stock there are left but a few small specialized and degenerate forms known as the duck-billed mole (*Ornithorhynchus*) and the spiny ant-eater (*Echidna*), which are now living in Australia.

Marine Vertebrates. — In previous chapters we have seen how the fresh-water vertebrates were forced to adapt themselves to the land, and how this habitat was attained only after a very long struggle. Now that the reptiles were firmly established on the land, however, we see them going back again to the water, not only intermittently to the rivers and lakes, but permanently into the seas and oceans, where there was a more certain food supply in abundance than is usually the case on the land. Dolphin-like reptiles, the ichthyosaurs, were present, though still rare (*Shastasaurus* of California), and a stock of long-necked, box-bodied

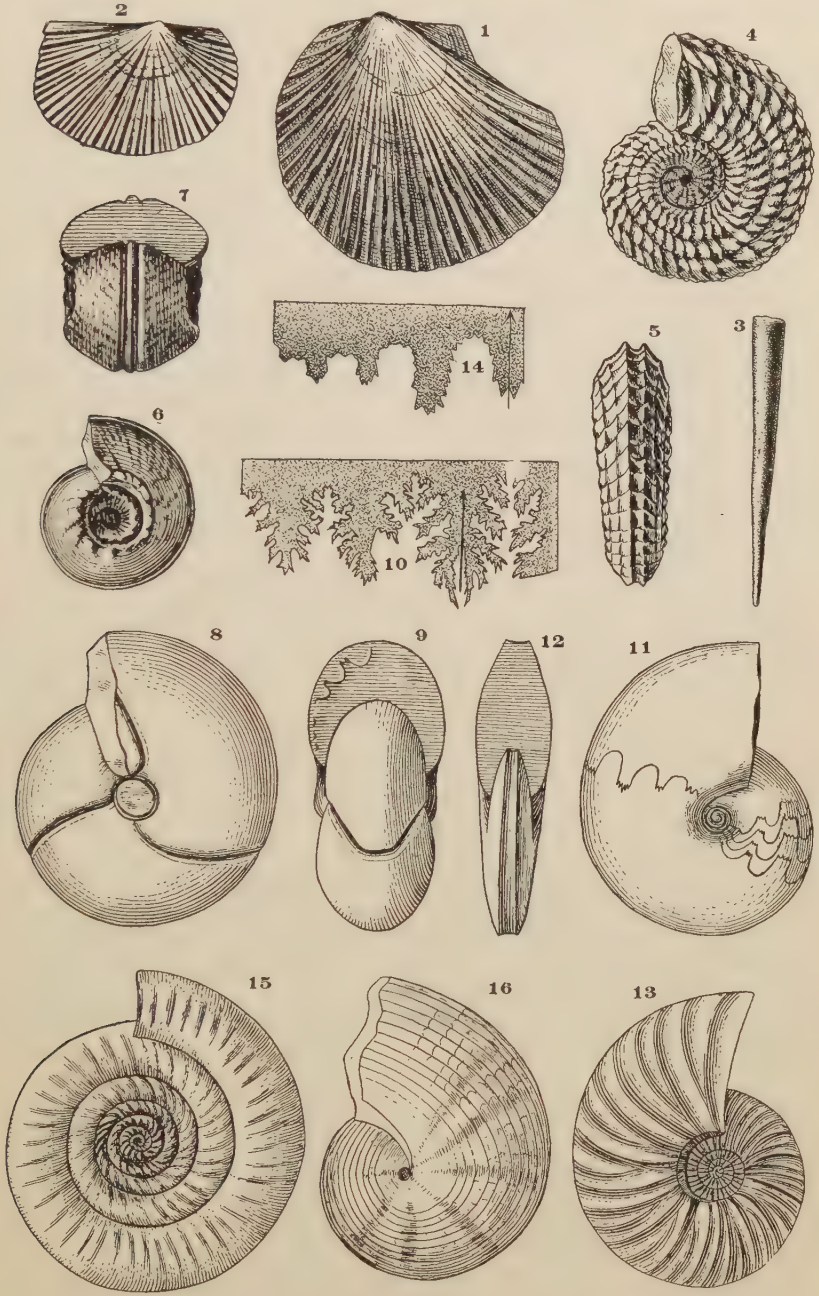


Plate 30. — Triassic bivalves (1, 2), belemnid (3), and ammonids (4–16). See Appendix B.

sea-dragons, the plesiosaurs (*Nothosaurus* of Germany), also had its start at this time, both of which groups became characteristic and abundant in the Jurassic and will be described in Chapter XLVII (see Figs. 469, 471). Here again we see the wonderful extent to which organisms can adapt themselves, for limbs have been changed from walking legs to swimming paddles, and the egg-laying method of rearing the young has been altered to that in which the young are born alive (viviparous development).

Marine Invertebrates. — The seas swarmed with ammonids in great variety (Pl. 30, Figs. 4–16). They were not only the most beautiful and characteristic animals of the Mesozoic seas, but also the highest expression of invertebrate evolution in agility and in predaceous and scavenging ability. Some of the species spread widely throughout the world. The squids originated in the Triassic (Pl. 30, Fig. 3) and were common in the Jurassic. Among the other shelled animals, the bivalves (Pl. 30, Figs. 1, 2) and siphonate gastropods were in the ascendancy. The brachiopods, though still common in Tethys, were very rare in the American Pacific faunas and have remained so up to the present time.

In the Upper Triassic appear the modern reef-building corals (Hexacoralla), which built limestones in Tethys up to 4000 feet thick, while reefs are known elsewhere with many identical species, as in the Himalayas, and in the eastern Pacific from California into Alaska. The modern echinids and lobsters also originated at this time, but were not conspicuous until later. Tethys and the western Pacific were the main centers of marine invertebrate evolution.

A survey of the life of the Triassic, contrasted with that of the Permian, shows that no greater change is recorded in all geologic time. This was the result of the marked physical changes undergone by the earth during the Appalachian Revolution at the close of the Paleozoic, one of the most critical periods in the history of the organic world.

CHAPTER XLVI

DINOSAURS, THE RULERS OF THE MESOZOIC

By Richard Swann Lull

The Mesozoic is truly the Age of Reptiles, but it might equally well be called the Age of Dinosaurs, for these animals were then the rulers of the dry land and the fresh waters. As they were so characteristic of all lands, and particularly of North America, during the Mesozoic, and as they are among the most interesting animals of all time, we must study them in some detail. What reptiles are and how they are related to the amphibia and the still lower vertebrates have been discussed in Chapter XLIV, and this knowledge should make the following account more easily understood.

The reptiles which most nearly paralleled the mammals of to-day were the dinosaurs, taking into consideration range of size, habits, and habitat. As the former were the dominant land animals of the Tertiary, so the latter were indisputably the ruling dynasty of the Mesozoic. In size they ranged from that of a chicken to gigantic monsters probably 80 feet in length. There were two main groups of dinosaurs, one herbivorous, the other carnivorous, both probably evolved from the same stock.

Carnivorous Dinosaurs (see Pls. 31–33). — The carnivorous dinosaurs, to which the name *Theropoda* (meaning *beast-footed*) has been given, were active rapacious forms running upon the hind limbs after the manner of many of the swifter lizards of the present, with hands and feet armed with increasingly powerful claws, and jaws with slightly curved dagger-like teeth, the sharp edges of which were often serrated to add to their efficiency as weapons of offense. So far as our knowledge goes, the carnivores were never defensively armored, though impressions of the actual skin are yet to be discovered; nor were they, with rare exceptions, endowed with horns or other bodily excrescences characteristic of the plant-feeding forms. Throughout their entire evolutionary career they relied for sustenance and defense upon strength or agility and, as in the great cats of to-day, upon power of tooth and claw.

The Theropoda shortly verged into three lines of descent, two of which remained carnivorous and terrestrial in habit, the one a

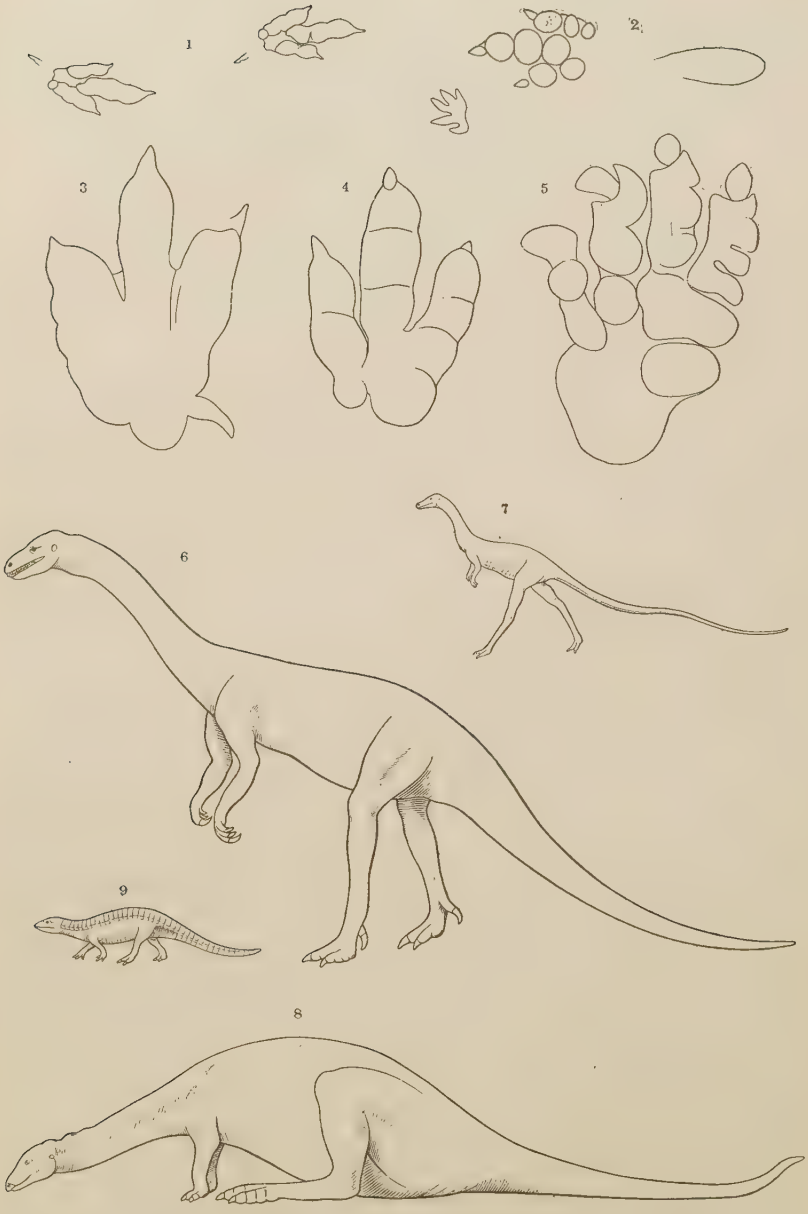


Plate 31. — American Triassic dinosaurs (1–5, footprints; 6, 7, carnivores; 8, herbivore), and a walking, crocodile-like reptile or aëtosaur (9). Restorations by Lull. See Appendix B.

smaller, more agile race preying upon the humbler reptiles, possibly upon the birds (see Pl. 32, Fig. 6), the other growing more and more ponderous as time went on, keeping pace with the increasing stature and armament of the vegetarian hosts. One peculiar feature of their evolution was the arrest of development of the fore limbs, until in the culminating forms they were so absurdly small that one can scarcely conjecture their use (Pl. 31, Fig. 7).

Sauropoda (see Pl. 32). — The third race which evolved from the theropodan stock had a relatively brief career. Its forms, because of increasing bulk, either did not attain the erect bipedal gait or reverted to the quadrupedal posture of their pre-dinosaurian ancestry; and then, the burden of the flesh becoming too great, they forsook the land and became partially if not wholly aquatic in habit. This group, the *Sauropoda* (meaning *reptile-footed*), is represented by several nearly complete specimens, notably by that of the majestic *Brontosaurus* (Pl. 32, Fig. 1), the thunder-saurian, a creature some three-score feet in length and ponderous of body, but with long, tapering neck and tail, as though an elephant were deprived of its normal terminals and provided with those of an enormous snake. The teeth, confined to the forward margins of the jaws, are clearly derivable from those of a carnivore, but blunted and often somewhat spoon-shaped, apparently so ill-fitted for any known type of food as to cause the widest conjecture as to the precise nature of their owner's diet. Flesh being hardly possible, fish has been suggested, but there is nothing among the associated fossils to indicate the amazing quantity which must have been required to supply the sustenance for growth and motive force in a creature whose weight approximated 37 tons! The final inference, therefore, is that some sort of plant life growing in great abundance and easy to secure formed the food, which was not masticated but detached by the claws and teeth and swallowed intact. The presence of smoothly polished stones, foreign to the local rock, which have been found within the ribs of occasional specimens, suggests the existence of a gizzard-like device for the reduction of this inert mass of food.

An elephant weighing 5 tons eats 100 pounds of hay and 25 pounds of grain for his day's ration; but as such food is in a comparatively concentrated form, it would require at least twice this weight of green fodder for an animal of the same size. The largest brontosaur probably weighed 37 tons, and it is estimated that its daily food must have been something like 700 pounds of plants.

But here we must curb our imagination a little and consider another point: the cold-blooded, sluggish reptiles, as we know them to-day, do not waste their energies in rapid movements, or in keeping the temperature of their bodies above

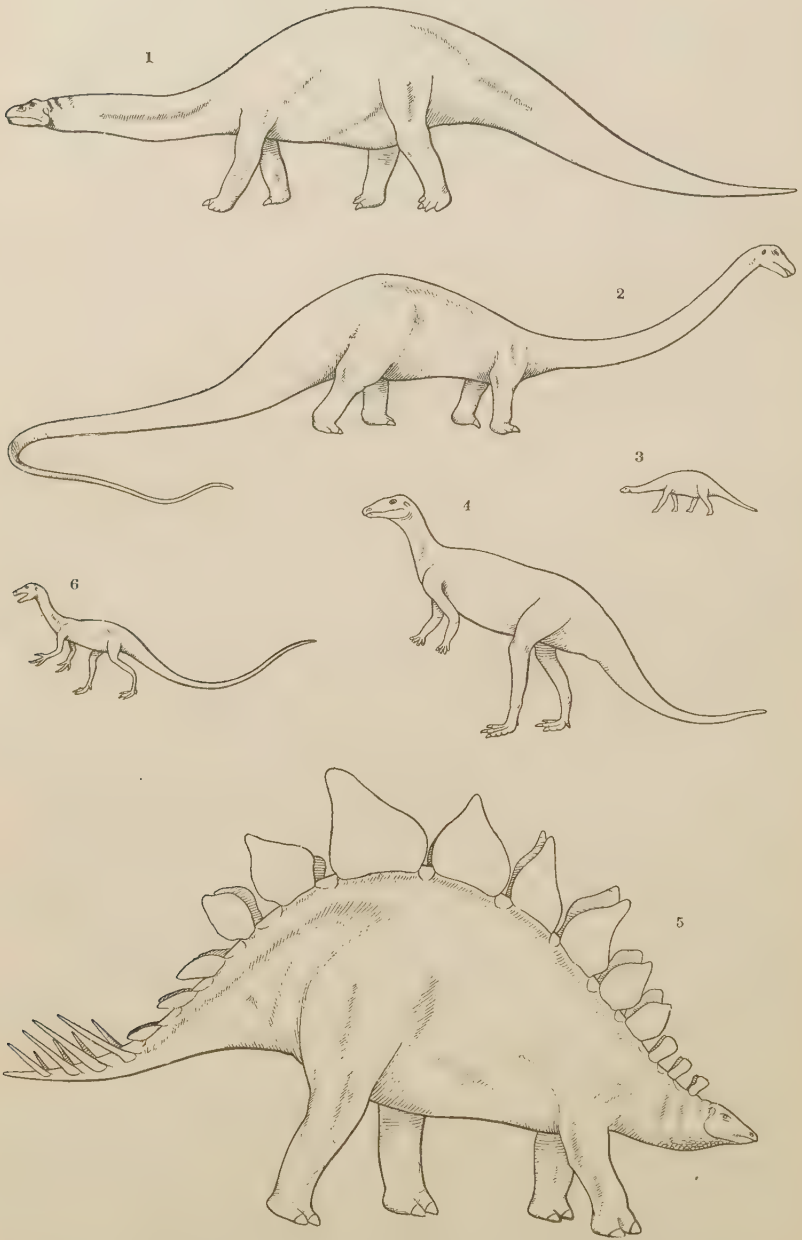


Plate 32. — American Comanchian dinosaurs (1–3, sauropods; 4, predentate; 5, armored; 6, carnivore). Restorations by Lull. See Appendix B.

that of the air, and so by no means require the amount of food needed by more active, warm-blooded animals. Hence these great dinosaurs may, after all, not have been gifted with such ravenous appetites as we fancy. (Lucas.)

The skeleton of one of these creatures is a marvel of mechanical design; the bones of the vertebral column are of the lightest possible construction consistent with strength, the bony material being laid down only where stresses arise and reduced to a minimum at other points. The assembled skeleton reminds one forcibly of a cantilever bridge borne on two massive piers — the limbs — between which the trunk represents the shorter channel span, and the long neck and tail the spans leading to the shores. Over the hips is a ridged anchorage formed by the coalescence of several vertebræ, for not only was this the point of origin of the tendons and sinews supporting the 30 feet of tail, but on occasion the whole forward portion of the body, fore limbs, and neck could be raised clear of the ground after the manner of a bascule bridge. In the refinement of its architecture the vertebral column is essentially Gothic, with arch, pillar, and buttress, and the freedom of design characteristic of the great fabrics of medieval time.

None of the known Sauropoda were small. *Brontosaurus* was of representative size; while another, *Diplodocus*, was lighter in build though long and slender, with the terminal half-score of its 80 feet of length an attenuated whip-lash-like appendage of unknown use (see Pl. 32, Fig. 2). The Sauropoda seem to have inhabited the sluggish waters of an imperfectly drained country, which supported their huge bulk, and supplied the aquatic plants upon which they fed. That they were armorless and defenseless seems certain, though impressions of a coarse integument are sometimes preserved. Their ponderous size, however, must have given them a certain immunity from attack, while their chosen haunts kept them out of competition with their fiercer kin. The western United States has produced the most perfect specimens, but a recent discovery at Tendaguru, German East Africa, has brought to light the most colossal individuals thus far recorded. Of these, perhaps the best known is *Brachiosaurus*, a genus which is also represented in North America. Some of the cervical vertebræ in this form are 3 to 4 feet in length and the total length of the neck has been given as 36 feet. The fore limbs were longer than the hind and the upper arm bone measured 6.5 feet. The tail, on the other hand, was relatively short. While extremely massive in build, the total length of this animal was about that of *Diplodocus*, probably not more than 80 feet, instead of 120 feet as the earlier accounts stated.

Predentate Dinosaurs (see Pls. 32, 33). — The other great dinosaurian race, in contrast to those above discussed, was exclusively plant-feeding throughout its known history, and, as a special adaptation to this form of diet, bore within the mouth a wonderful battery of teeth. The front of the mouth, contrary to that of the Sauropoda, was toothless except in the most primitive forms, but in compensation had a very efficient cropping device in the form of a turtle-like beak for securing the food. In the rear of the jaws, on the other hand, were deep grooves which lodged vertical rows of successional teeth, of which the outermost two or three in each row pushed against their fellows in the opposing jaw, while those lying deeper migrated outward to replace such as were worn out and lost through use. The teeth were few and simple at first, becoming, as time went on, more and more numerous, until in *Trachodon* (Pl. 33, Fig. 6), the terminal member of one line, the dental battery contained no fewer than two thousand teeth. These predentate dinosaurs, so called from the peculiar toothless bone that united the two halves of the lower jaw, soon differentiated into two distinct races, the unarmored bipeds and the armored quadrupeds, while from the latter arose a third, the horned dinosaurs or Ceratopsia.

Bird-footed Dinosaurs. — Of these three types, the unarmored Ornithopoda, or bird-footed dinosaurs, depending for defense largely upon fleetness of foot, were the least specialized, and in their evolution paralleled the carnivores almost precisely (Pl. 32, Fig. 6). Like the latter they were divided into a lesser and a greater race, some being of small proportions, 4 or 5 feet in length, while others reached a length of 40 feet. A fortunate discovery made in Niobrara County, Wyoming, in 1908, brought to light a specimen of *Trachodon* which, because of the marvellous preservation, permits an almost perfect mental reconstruction of the animal. The dinosaur had apparently died where it could be gradually desiccated under the heat of a tropical sun until the skin and much of the flesh and tendons had shrunken down upon the bones. In places the skin is thrown into the finest wrinklings, showing it to have been as thin as that of a python; but in contrast to that of the snake, it bore not scales but tubercles, some rather large, others excessively fine, but showing a distinctive arrangement. There is, however, over the entire body no trace of defensive armor. The curious webbed character of the hand and the presence, in other specimens, of a powerful compressed tail, point to an animal with the swimming powers of an alligator, but still retaining the ability to travel rapidly on land. Hence *Trachodon* was able to avoid the onslaught

of the omnipresent carnivore, not alone by its speed ashore, but by taking to the water when hard pressed.

Stegosauria (see Pl. 32). — But all herbivorous dinosaurs were not of this defenseless type. The second race, the Stegosauria, or armored dinosaurs, encased the body in an almost impregnable armor, at first quite similar to that of existing crocodiles, whose hide with its contained plates of bone will turn any but the most powerful or skillfully placed rifle bullet. Later the armor became more and more massive, the bony elements being welded into a broad protective shield or carapace covering the creature's back, while the heavily armored tail was like a huge battle mace. As an animated citadel, these animals must have been practically unassailable, for they survived until the very close of the dinosaurian reign.

The most remarkable feature of *Stegosaurus* (Pl. 32, Fig. 5) is perhaps its extremely diminutive brain, which had an estimated weight of but 2.5 ounces, whereas the total weight of the animal must have exceeded that of the largest of living elephants, the brain of which is over twenty times as great. In comparing the relative intelligence of the two, one has to bear in mind the great preponderance of the cerebrum, the seat of the intellect, over the other part of the elephantine brain, whereas in *Stegosaurus* it constituted scarcely more than a third of the entire brain weight. On the other hand, the nerve canal in the sacrum, that portion of the vertebral column which lies between the hips, is of startling dimensions and shows that this part of the spinal cord from which the nerves went out to the great muscles of the hind limbs and tail was not less than twenty times the mass of the brain. Mentally, *Stegosaurus* was superlatively stupid, depending for defense upon the automatic control of the great muscles after the feeble glimmer of thought had given the initial impulse.

In *Trachodon* the brain is smaller than a man's fist and weighs less than a pound. *Brontosaurus* had a brain but little larger, while the large-headed *Triceratops*, to be described later on, with over 10 tons of flesh, possessed a brain weighing not over 2 pounds. Man has an average of about 2 pounds of brain to 100 pounds of total weight, while the dinosaurs did not have one-fourth of this amount of brain to the ton. Or with other comparisons, the brain of the average dinosaur was in proportion to bulk of body a tenth the size of that of a crocodile.

How much of what we term intelligence could such a creature possess? Probably just enough to have eaten when it was hungry, anything more being superfluous. However, intelligence is one thing, life another, and the spinal cord, with its supply of nerve-substance, doubtless looked after the mere mechanical functions of life, and while even the spinal cord is in many cases quite small, the sacral portion is twenty times the bulk of the puny brain. (Lucas.)

With races, as with individuals, there are periods of youth, of maturity, and of old age, terminated in the one by extinction, in the other by death; and as a man bowed down by the weight of years shows unmistakable signs of senility, so the senescence of the race is as clearly indicated to the practised eye by features which in the one case as in the other point to impending dissolution. Among the more striking of these racial old-age characteristics is a relative increase in size beyond the average, and the growth of excrescences of various sorts on diverse portions of the frame, such as the antlers of the deer. *Stegosaurus* in its immense, ill-proportioned bulk, the huge, erect bony plates along its spine, and the spike-like weapons with which its tail was embellished, shows these characters in the extreme, and, speaking metaphorically, is the embodiment of the death agony of a race.

Ceratopsia (see Pl. 33). — The final group of plant-feeders, the horned dinosaurs, mark the culmination of medieval geologic time, for the brief record of their evolution is confined to the latest Mesozoic rocks. These forms had a huge head — in all other types the reverse is true — upon which were horns, two, three, or five in number, borne upon the nose or above the eyes. The neck was protected by a wide-spreading flange of massive bone, typically with serrate edges and invested in a close-fitting covering of horny substance as implied by deep blood-vessel impressions in its outer surface. In the forms in which the nasal horn was dominant, the crest was imperfect, the animal doubtless charging as a rhinoceros might and impaling its enemy with a sweeping upward thrust of its head; while those whose frontal horns were larger were animals of greater bulk and in them the crest reached its highest efficiency, so that a head-on charge of two rival males was comparable to a joust between panoplied knights, the mighty impact of the lance-like horns being deflected by the shield-like flange. That the ceratopsians did fight, and that most desperately, is shown in the grievous "old dints of deepe woundes" that remain on many a skull, fractured and healed jaws and horns, pierced crania and crests. As these were only the relatively few wounds which penetrated the bone, what battle-scarred old veterans they must have been after their century or more of life!

Unlike man and the higher vertebrates, reptiles and fishes do not have a maximum standard of size which is soon reached and rarely exceeded, but continue to grow throughout life, so that the size of a turtle, a crocodile, or a dinosaur tells something of the duration of its life. If tortoises may attain an age of several hundred years, why should not a dinosaur grow to be much older? (Lucas.)

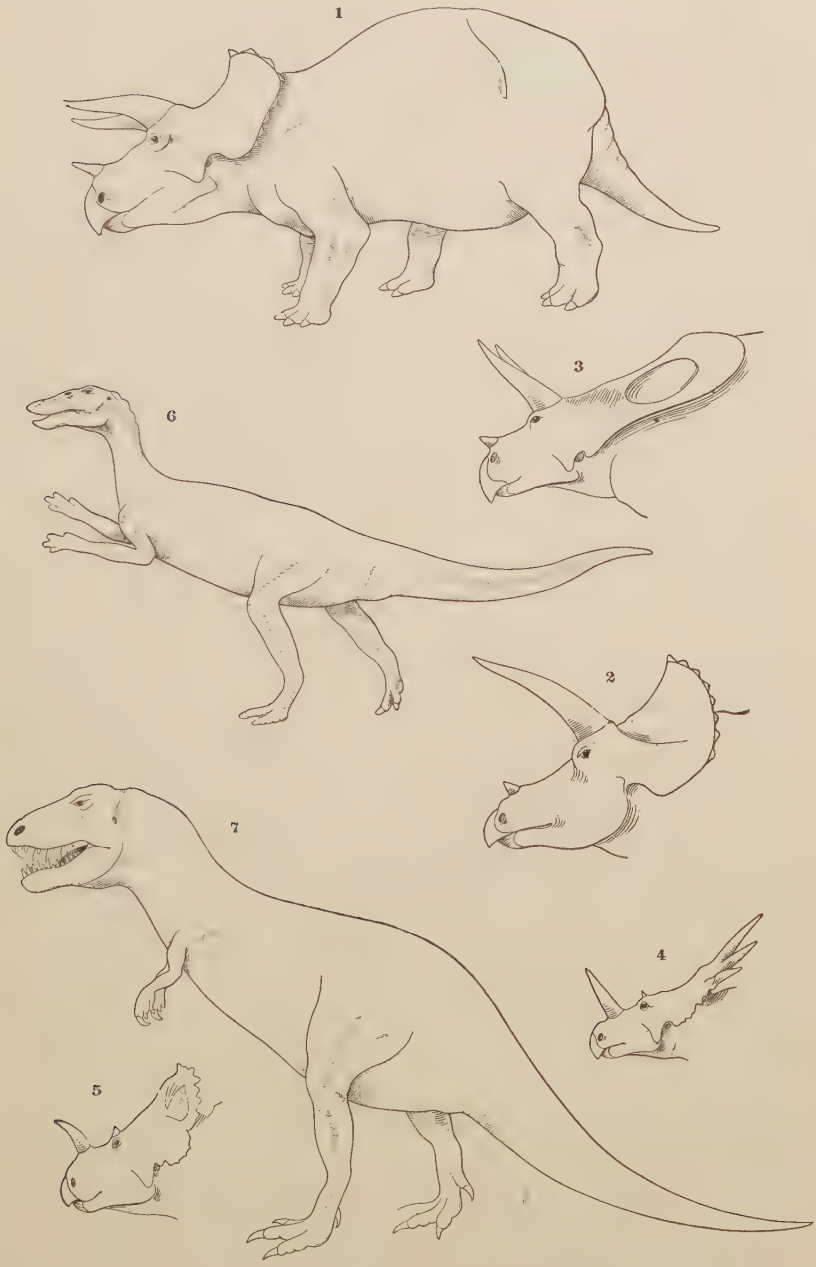


Plate 33. — American Cretaceous dinosaurs (1–5, ceratopsians; 6, predentate; 7, carnivore). Restorations by Lull. See Appendix B.

Did Dinosaurs Lay Eggs? — A point still unsettled is whether the dinosaurs were oviparous or viviparous — did they lay eggs, or were the young born alive? If we are guided by analogy, it might be supposed that, like crocodiles and alligators, these reptiles laid eggs and left them to be hatched by the heat of the sun. As no fossil Mesozoic eggs have as yet been found, the question cannot be answered, though it appears probable that they laid eggs like most other reptiles.

Relation of Dinosaurs to Birds. — The dinosaurs have as many points of structure in common with birds as they do with crocodiles. A very obvious feature of the bird-footed dinosaurs is a three-toed foot; but while this is so very bird-like in appearance, it really is not so important a character as the structure of the shoulder and hip bones and that of the ankle joint, which are extraordinarily like those of a bird. In ourselves and in other mammals, as well as in existing reptiles, the ankle joint is between the bones of the ankle and those of the lower portion of the leg, the tibia and fibula. But in birds and in dinosaurs, some of the ankle bones are united with the leg bones, so that the ankle joint comes in the middle of the ankle itself, and this character is not possessed by other animals, except a few other reptiles.

It is now held that the bird-footed herbivorous dinosaurs (Ornithopoda) and the birds were derived from the same reptilian stock and that in the birds the small, grasping, front limbs have been transformed into wings. This evolution took place earlier than the Upper Jurassic, where undoubted birds — reptilian birds — are known, and it is probable that the beginning goes back to the Triassic. How the evolution went on is not known.

Rise and Succession of Dinosaurs. — As in the history of nations the members of various human races intermingle, so the dinosaurs are interwoven not alone with the various types of their own stock, but with the other kinds of animals and plants which together with physical conditions go to make up the environing complex. A summary of the changing life conditions with their influence on the successive dinosaurian societies is necessary to an understanding of their evolution.

The first relics of dinosaurian life are found in the Middle Triassic rocks of central Europe, though as they appear shortly after those in North America one is led to infer that the initial evolution occurred in Eria. Ancestrally, the dinosaurs were doubtless water-loving quadrupeds remotely related to the crocodiles; but the increasing aridity of climate, clearly indicated by the character of the geologic sediments, placed a high premium on ability to travel rapidly and far in search of food and drink, and may well have been the impelling force that raised these creatures erect from the prone

gait and posture of their progenitors and stimulated their rapid evolution into the several types.

In contrast to marine deposits continental formations are scarce, and yet they alone, with rare exceptions, contain the remains of terrestrial animals. We are given, however, aside from scattered records, three or four vivid pictures of the environment, both physical and organic, wherein the dinosaurs dwelt. Fortunately for us, these glimpses are given in the early stages, in the middle, and at the close of the dinosaurian career, showing the race in the period of its youth, its full maturity, and in its extreme old age.

Late Triassic (see Pl. 31). — The scene of the first of these pictures is laid in what is now the Connecticut valley; the time, late Triassic. Here one must imagine a broad valley rimmed by enviroining uplands of older rocks, in its climate and sparse vegetation similar to the conditions to be seen to-day by the traveller through the arid regions of the great Southwest. The plant life is sombre: huge scouring rushes, ferns, and pines, with no flowering plants to break the monotony of the dull dust-covered greens. Here and there are dry stream beds carrying at times great floods, while occasionally there are formed extensive bodies of water with characteristic insects, fishes, and crocodile-like reptiles. In the Connecticut valley deposits, skeletons are extremely rare and the few which have been found are largely those of dinosaurs, and in but three or four localities. The footprints, however, for which this region is justly famous, are numberless, and indicate hosts of creatures of more than a hundred kinds, a fuller record of vertebrate life than in any other time and place in the geologic past (Pl. 31, Figs. 1–5). The dinosaurs are mainly carnivorous, though impressions of the feet of herbivores give indubitable evidence of their presence at this time.

During the long Jurassic period, the second division of the Reptilian age, the known fossil-bearing rocks are so largely of marine origin that, except for rare instances where the animal has accidentally been carried into the sea, the record of terrestrial life is almost a blank.

Comanchian (see Pl. 32). — In the Comanchian, however, we have another glimpse of well nigh the entire assemblage of dinosaurian life. The scenes are laid along the eastern United States from Maryland southward, but more notably in Wyoming, Colorado, and Utah, and in the Old World in southern England and northern France and Belgium. In contrast to the aridity of the former scene, the climate is now moist, and the eye ranges over an exten-

sive, low-lying country with misty bayous in which the huge Sauropoda, now in the flower of their evolution, find retreat. The vegetation, though far more luxuriant, is of the same monotonous type as that of the Trias. Here are predentate dinosaurs, armored and unarmored, and while the former are still relatively few, *Stegosaurus* already shows the senile grotesqueness which heralds its extinction. Carnivores, small and large, now in their millennium of numbers and differentiation, ceaselessly seek their prey.

Late Cretaceous (see Pl. 33). — Late Cretaceous time ushers in the third and last scene, of much the same geographic extent as before, but with the sharp contrast of an essentially modernized flora, for the forests now contain many familiar trees and plants, though often in unfamiliar combinations. Again our record is of low-lying country — stretches of everglade and swamp lands with higher areas between — but the denizens have changed; for while the carnivores are now in their maximum of size, the Sauropoda, except for possible survivors in far-off Patagonia, have run their course and died without issue. Unarmored dinosaurs are in their prime, only in rare cases showing indications of degeneracy, while the relatively few heavily armored types are represented by the most impregnable of their race. The horned dinosaurs, apparently exclusively American, begin and end their brief evolutionary career.

Dinosaur Extinction. — One of the most inexplicable of events is the dramatic extinction of this mighty race, for in the rocks of accepted Tertiary age not a single trace of them remains. One student has argued internecine warfare amongst the dinosaurs themselves; another, the destructive slaughter, not of adults but of the young, possibly while yet in the egg, by small bloodthirsty mammals; yet another, change of climate either by the diminution of the necessary heat without which no reptilian race may thrive, or of the moisture with an accompanying change of vegetation. These are all conjectural causes of extinction; but this we know, that with the extensive changes in the elevation of land areas which mark the close of the Mesozoic, came the draining of the great inland Cretaceous seas along the low-lying shores of which the dinosaurs had their home, and with the consequent restriction of old haunts came the blotting out of a heroic race. Their career was not a brief one, for the duration of their recorded evolution was thrice that of the subsequent mammalian age. They do not represent a futile attempt on the part of nature to people the world with creatures of insignificant moment, but are comparable in majestic

rise, slow culmination, and dramatic fall to the greatest nations of antiquity.

Nevertheless their passing was of the utmost importance to a higher race. During the eons of the Mesozoic, from late Triassic time until its close, the mammals, including the remote progenitors of humanity, were in existence, but held in such effective check that their evolutionary progress was practically insignificant. This curb is strikingly illustrated by the wonderful series of tiny jaws and teeth of these diminutive creatures found, in the Comanchian of Wyoming, in actual association with the single tooth of a carnivorous dinosaur, many times the bulk of the largest mammalian jaw.

The removal of this check resulted in the speedy evolution of the archaic mammals into flesh- and plant-feeders, slow-moving and swift. These, because of radical defects of brain and feet and teeth, had but a brief allotted span, and were in their turn displaced by the immigrating hordes of modernized mammals which were to be the rulers of the earth until forced to own the dominance of man.

CHAPTER XLVII

THE JURASSIC PERIOD AND THE MANY KINDS OF REPTILES

In Europe, over the Triassic lies the widely distributed and usually but little disturbed Jurassic, a great series of limestones and shaly limestones attaining to thicknesses of over 3250 feet. The high lands that were made during the close of the Paleozoic had now vanished, and extensive epeiric seas, with a life that was astonishingly rich and varied, gradually spread over Europe. Probably as many kinds of fossils are known from Jurassic rocks alone as from all the other Mesozoic strata combined, and because of this prevalence of organic remains, these formations have been the training grounds for many European stratigraphers and paleontologists.

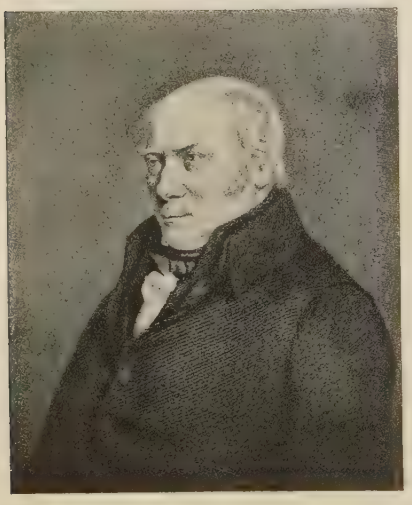


Fig. 463.—William ("Strata") Smith (1769–1839) at the age of sixty-nine. Father of English Geology, and of Stratigraphy.

The Term Jurassic. — In England, these deposits furnished fossils to William Smith, the Father of Stratigraphic Geology (Fig. 463), who was the first to discern in them a value as aids in determining the age of the containing strata. In fact, it is from the Jurassic deposits of England and Germany that the principles upon which Stratigraphic Geology depends have been worked out. At the beginning of the past century, Smith called this system the Oolite series, because so many of its formations abound in oolite structures, so-called from their resemblance to the roe of a fish (see page 275). The earliest division he named Lias, the middle Dogger, and the upper Malm; these are quarrymen's names for local kinds of rock and all of them are still in use, especially in England.

It is interesting to digress here a little, and to note that in the latter country the Jurassic passes through five cycles of sedimentary deposition, that is, the rocks pass five times through the cycle from arenaceous to argillaceous to calcareous strata (Geikie). At one time it was widely held that periods should be based on sedimentary cycles, but the fallacy of this conclusion is seen in that the Jurassic period has within itself five such cycles.

However, as none of the terms used by Smith were based on a definite exposure of rocks, the French geologist, Alexandre Brongniart, in 1829 proposed the name Jurassic for the system, establishing it on the equivalent formations exposed in the Jura Mountains, which lie between France and Switzerland.

Divisions of the European Jurassic. — In Germany, Von Buch in 1839 divided the Jurassic on the basis of rock character into Black (lower), Brown (middle), and White (upper) Jurassic. Later on Quenstedt took up a detailed study of the contained fossils, and in 1858 divided the system into eighteen biologic zones. He was not only a good teacher, but an enthusiastic and genial man, and thus was able to enlist in his work the local collectors of fossils and even the farmers; to this day it is said that the peasants point out his divisions on their farms. Oppel, his student and successor, finally divided the Jurassic into thirty-three zones, many of which are known to have a very wide distribution. More than forty divisions are now recognized, and Buckman predicts that from eighty-five to one hundred biologic divisions (hæmeræ) will be eventually defined. These facts are recited for the dual purpose of showing (1) to what degree of refinement stratigraphy may be developed when an abundance of fossils is present, and (2) that the Jurassic system has so far maintained itself as the best system for exhibiting the principles of zonal correlation.

From the studies of the abundant Jurassic marine faunas came also the first clear ideas of climatic zones in Geology and of world paleogeographic maps, through the work of Professor Neumayr of Vienna. As the result of a long study of the ammonids and their geographic distribution, he came to the conclusion in 1883 that the earth in Jurassic time had clearly marked equatorial, temperate, and cool polar climates, agreeing in the main with the present occurrences of the same zones. The consensus of opinion to-day is that these are representative rather of faunal realms than of temperature belts. On the other hand, it is admitted that there were in the Jurassic clearly marked temperature zones.

North America, however, stands in strong contrast to the European Jurassic development, for the record is one of erosion

and peneplanation over three fourths of the eastern part of this continent. It was only along the Pacific border that the ocean invaded the land and for a limited time extended east as far as Wyoming and Colorado. Probably less than 600 kinds of Jurassic fossils have been described from North America, while Europe has made known nearly 15,000 forms.

Subdivisions of the Jurassic

		Marine Phase of Europe	American Pacific	Cordilleran	American Atlantic
Jurassic	Upper	Portlandian Kimmeridgian Corallian	Colfax, Mariposa } Auriferous	Absent	No stratigraphic record
	Middle	Oxfordian Callovian Bathonian Bajocian	Hinchman Mormon	Sundance Absent	
	Lower	Lias	Hardgrave		

Jurassic Events in Eastern North America

Absence of Jurassic Deposits. — Until recently it was held by many geologists that certain rather local deposits, of continental origin, occurring on the Piedmont Plateau and extending from New Jersey into Virginia, were of Jurassic age. This, the Potomac formation, is now held, on the basis of its entombed plants and dinosaurs, to be of Comanchian time.

Jurassic Erosion Cycle. — In a previous chapter we saw that the Triassic period in eastern North America closed with the Palisade Disturbance, a movement that resulted in the making of block mountains probably as high as the present Sierra Nevadas. Accordingly, Jurassic time opened here with active erosion, and whatever continental deposits were formed at the time were swept into the oceanic basins. Therefore Jurassic time throughout the greater part of North America was one of erosion and without record of the sea or even of the fresh waters. All of the sediments were delivered into the Atlantic beyond the present eastern and southern margins of the continent. This erosion cycle brought about the final transformation from the old topographic expression of high Appalachian and lower Palisade mountains to a nearly base-leveled land, and it was this peneplanation that prepared the way for the next overlap of the Atlantic Ocean, in Comanchian time.

Jurassic of the Cordilleran-Mexican Regions

Northern Pacific Border Area. — In the chapter on the Triassic it was shown that the period closed with crustal warping and deformation all along the entire Pacific border of North America, and that mountain making on a considerable scale took place at least throughout Alaska. In consequence the sea was removed everywhere from the continent, at least from those parts of it now accessible to the geologist. How long this break in sedimentation lasted is not yet known.

The Pacific Ocean again began to invade North America early in Jurassic time, sparingly in the Aleutian Peninsula, the Cook Inlet country of Alaska, and across Vancouver Island. The widest extension at this time occurred in the Californian sea of Oregon, California, and Nevada, where the crustal movements during the Triassic had been only of warping significance (Pl. 34). Of Middle Jurassic events little is as yet well known, other than that the Lower Jurassic of Alaska (1000 to 4000 feet) continues unbroken into the Middle (1500 to 2000 feet) and Upper Jurassic (5000 feet). The total thickness of the marine Jurassic in Alaska exceeds 10,000 feet and consists essentially of coarse deposits, such as tuffs, conglomerates, sandstones, and shales, with lava (andesitic) flows near the top of the series. This is largely the material from the Chitistone mountains formed at the close of the Triassic. The Jurassic series in Alaska along the Pacific border is fossiliferous throughout, though by no means to the extent that is true of Europe. (Stanton and Martin.)

Arctic Alaska. — A very thick series of continental deposits of early Upper Jurassic age has been discovered by Collier in the Cape Lisburne region of Alaska (Pl. 34, Fig. B). The strata, which have been given the name of the Corwin series, consist in the main of coarse deposits, shales with sandstones and some conglomerates, attaining to at least 15,000 feet in thickness, in which there are from forty to fifty low-grade non-coking coal beds, varying in depth from a few inches to 30 feet. Ten beds are each over 4 feet thick, and the total thickness of all the coal seen is 137 feet. The coal is of better grade than lignite. Below these coals are other workable Paleozoic non-coking coals that are of Lower Carboniferous age.

Californian Sea (Walcott, 1894). — The Jurassic marine deposits are widely spread over the states of California, Oregon, and Nevada (Pl. 34). Apparently most or all of Jurassic time is represented, but the detail of the formations is well known only locally, even

though the much-sought-after placer gold of California originally was derived from rocks of this period, the Mariposa and Auriferous slates (Gold Belt series). These Upper Jurassic formations of northern California and the adjacent part of Oregon are essentially sandstones and shales, with very little of limestone and more of tuffaceous conglomerates (500 feet). In places the thickness is 2000 feet, rising to over 6000 feet elsewhere in California, and if the Lower Knoxville strata of 10,000 feet thickness, with their Jurassic flora, belong here, the maximum thickness will rise considerably above the last mentioned figure. In the Humboldt Range of Nevada there are from 1500 to 2000 feet of basal Jurassic (Liassic) limestone, followed above by 4000 feet of slates. Evidently the Upper Jurassic material was derived from a high land, and in places these formations are seen to rest unconformably on the Triassic.

The faunas are always small ones and corals are locally common. During early and middle Jurassic time, the faunal migrations were from the warmer waters of the south, but in the Upper Jurassic (Mariposa, Lower Knoxville) the life was clearly of northern Pacific origin and a part of the boreal or cooler water faunas.

Logan Sea. — Toward the close of the Middle Jurassic, the northern Pacific, with a cool-water fauna, began to spread widely over Alaska and British Columbia and into the states of Montana, Idaho, Wyoming, Colorado, and Utah (Pl. 34, Fig. B). In the Great Plains region the deposits of Logan sea (named after W. N. Logan, who first described its extent) have an average thickness varying between 200 and 400 feet, but increasing to the west to upward of 1000 feet, and in southwestern Wyoming to 3500 feet. The nature of the deposits changes from place to place, and they consist of sandy clays, shaly marls, impure limestones, and sandstones. The cross-bedded sandstones, the changeable sediments, and the universal presence of oysters indicate that the sea was a shallow one, and further, that it flowed over a warped land eroded to a low relief.

Fig. 464. — Characteristic boreal Jurassic bivalve, *Aucella pallasii*.

The fauna is a small, monotonous one, probably not exceeding seventy-five species, and is almost altogether made up of Mollusca, including a few ammonids and squids. The assemblage indicates that the waters did not belong to the open sea, but were those of a large bay and of boreal origin. Among vertebrates, the common forms were the dolphin-like reptiles called ichthyosaurs (page 856), while

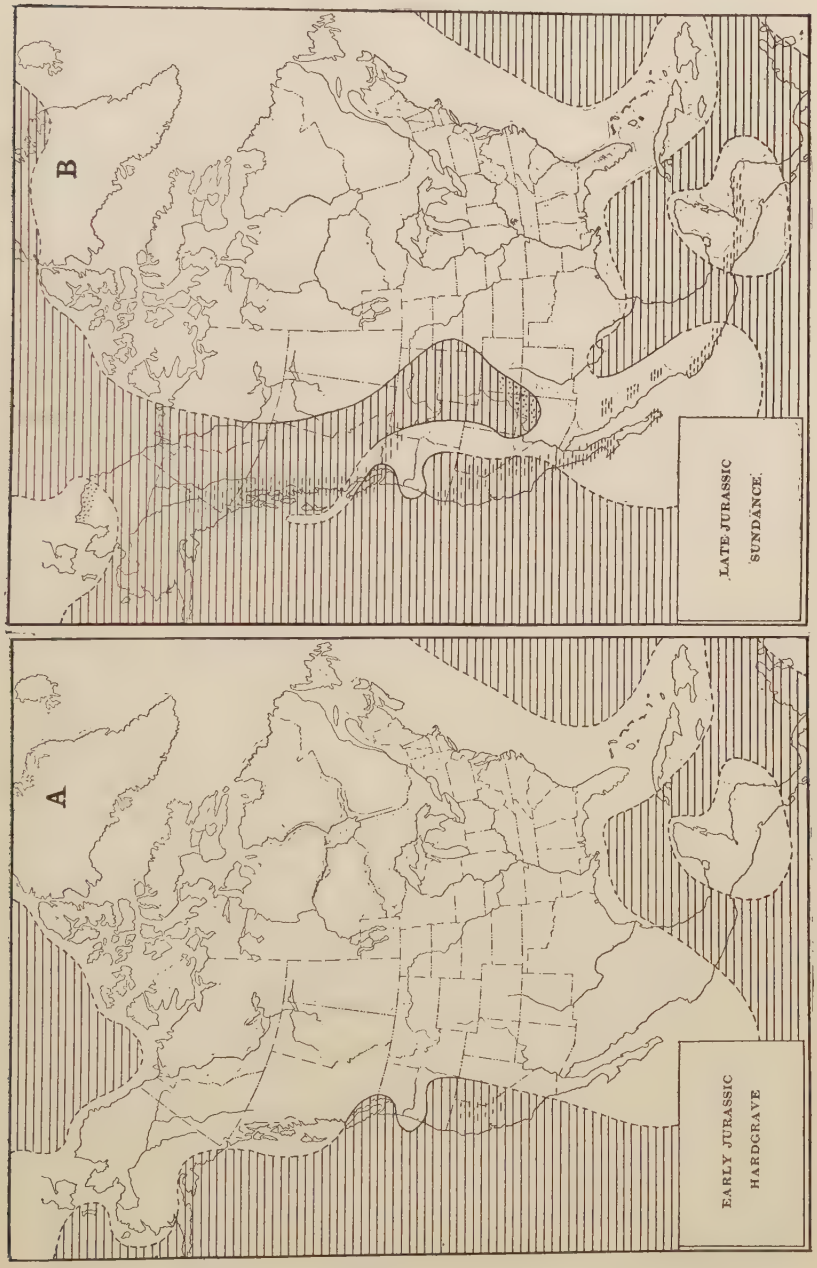


Plate 34. — Jurassic paleogeography. Areas of bathyliths and elevation indicated by dashed lines.

the plesiosaurs (page 857) were rare. The submergence was of short duration and vanished early in the Upper Jurassic before the Alaskan waters began to abound in the boreal bivalves known as *Aucella* (Fig. 464).

Mexico. — Through all of Paleozoic time the greater portion of Mexico was land, and formed a part of the ancient continent Columbia (Fig. 365). Late in the Triassic the Gulf of Mexico spread for the first time over northern Mexico. In the late Middle Jurassic, the greater part of southern and eastern Mexico and southern Texas was flooded by the Gulf and the Pacific, and we shall see further periodic floodings of this land throughout later Mesozoic time (see Pl. 34). The sediments in the main are limestones, with but little of calcareous shales. The thickness of the formations ranges between 1000 and 2000 feet, and they abound in ammonids.

This Mexican subsidence is correlated by Burckhardt with the late Upper Jurassic. The faunas are unlike those of California and have decided European connections, since of the eighty-five ammonids described, eight are identical with those of central Europe and northern Russia, while eleven other forms are closely related. This shows that the western end of Tethys was open into the northern Atlantic and that the faunas migrated along the shores of Gondwana into Mexico.

Volcanic Activity. — In a previous chapter it was stated that volcanoes were active along the Pacific border of North America during Middle and early Upper Triassic time. Similar activity began again locally early in the Jurassic and continued throughout the period, becoming even more marked toward its close than at any time during the Triassic (see Pl. 34). The eruptions were in part submarine, and in part issued from vents situated along the shore line but following in the main the distribution of the Triassic volcanoes. In these lavas basic greenstones, that is, altered basalts, now predominate. (Lindgren.)

Sierra Nevada Disturbance. — At the close of the Jurassic the Sierra Nevadas, the Coast Range of California and the Humboldt Range of Nevada were elevated; also the Cascade and Klamath mountains farther north. These did not then have more than half their present height. The making of the Sierra Nevada Mountains at this time was pointed out by Whitney in 1864 and further described by Dana. Blackwelder (1914) has called this the Nevadian movement, while Smith terms it the Cordilleran Revolution, but the deformation of the crust did not have the extent of a world-wide revolution. Although the mountains mentioned are the regions of most active deformation, it seems probable that movements more or less marked took place from Mexico into southern Alaska. This conclusion is drawn not only from the wide distri-

bution of late Jurassic bathyliths, but also from the fact that at no subsequent time did the Pacific Ocean again spread over the United States so widely as it had previously done.

With the rise of the Sierra Nevadas, there also apparently began the formation of a new trough to the east of the folded area, the *Coloradoan geosyncline*, of which much will be said in discussing the events of the Cretaceous. During Comanchian time, however, this was not decidedly a sinking field.

While the Pacific border of North America was being folded, the earth-shell was also invaded by deep-seated igneous rocks (granodiorite) on a large scale. Magmas in great volume were intruded, forming the great chain of bathyliths now exposed by erosion along the Pacific border from Lower California to the Alaskan Peninsula (see Pl. 34). In comparison with this intrusion, all post-Proterozoic igneous phenomena fade into insignificance. The bathylith of the Sierra Nevada is 400 miles long and has a maximum width of 80 miles, while on the International Boundary there are twelve bathyliths that have a combined width of 350 miles. Farther north appears the Coast Range bathylith, probably the greatest single intrusive mass known, which extends unbroken for 1100 miles into the southern Yukon country, with a width of from 30 to 120 miles. It is thought that while these intrusions began in Middle Jurassic time, the main injections took place at the close of the period, extending into Comanchian time, and that less significant upwellings went on even to the close of the Mesozoic era. (Lindgren, and LeRoy.)

The gold-bearing veins of quartz in the rocks of the Sierra Nevadas have formed as a consequence of the upturning. The wrenching of the strata opened the leaves of the slates and also made great intersecting fissures. The opened spaces and fissures became filled with silica (quartz) deposited by the heated solutions coming from the bathyliths below, which also brought with them the ores now found in the veins. Some of these auriferous quartz veins have a width of 10 to 40 feet. Their erosion has furnished the gold found in the placers (see page 399).

Climate of Jurassic Time

Earliest Jurassic or Lias. — We have seen that in Triassic time volcanoes and lava flows occurred in many places, and that at the close of the period there was considerable mountain making along the northern Pacific border of North America. These movements do not seem to have been of sufficient magnitude to bring on a marked reduction in the climate of the world, and yet a cooled climate is indicated among the animals, as will be shown later.

Students of ammonids say that the closing time of the Triassic was a particularly critical one for this group. Of the more than one thousand known species of Triassic ammonids, not one continued to live into the Jurassic, and the later fullness was developed out of a single family of Triassic time. This extinction and marked evolution along a single line points to marked climatic alterations.

In the Lias there are known 415 species of insects, which remind one much of modern forms. Nearly all were dwarf species, smaller than similar insects living to-day in the same latitude and far smaller than those of the earlier Paleozoic or Upper Jurassic. Handlirsch is positive that this uniform dwarfing of the Liassic insects was due to a reduction of the temperature, and that the climate was then cool and like that of present North Europe. The climate, he states, was certainly cooler than that of the Middle Triassic or of the Upper Jurassic.

With this dwarfing of the insects, and the vanishing of the late Triassic ammonids, there is also to be noted a marked quantitative reduction and geographic restriction among the reef corals of Liassic time. We are therefore seemingly warranted in concluding that the cooling of the climate in latest Triassic and early Jurassic time was not local in character, but was rather of a wide-spread nature.

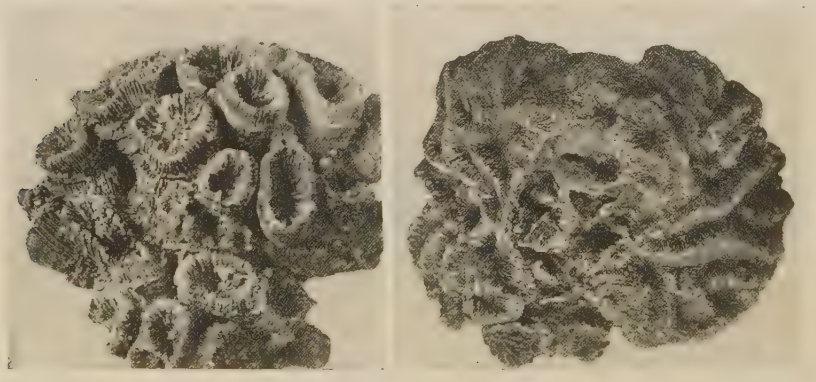


Fig. 465. — Two kinds of Jurassic reef-making Hexacoralla. On right, *Latomœandra seriata;* on left, *Thecosmilia trichotoma.*

Late Jurassic. — The very extensive distribution of Jurassic ammonids shows that there were at that time clearly marked temperature zones, that is, a very wide medial warm-water area, embracing the present equatorial and temperate zones, with cooler but not cold water in the polar areas. That the oceanic waters of

Middle and Upper Jurassic times were warm throughout the greater part of the world is seen not only in the very great abundance of marine life, but also in the far northern distribution of many ammonids, corals (Fig. 465), and marine reptiles. Jurassic rocks often abound in reefs made by sponges, corals, and bryozoans. Jurassic corals occur 2000 miles north of the present occurrence of similar forms. The plant distribution shows clearly that the floras were cosmopolitan and of a moist, warm, and probably subtropical climate. The insects of the Upper Jurassic were again large and abundant, thus confirming the climatic evidence deduced from the plants. In other words, the temperature of late Jurassic time was considerably higher than it had been earlier in the period.

Life of the Jurassic

Land Floras. — The Jurassic floras were truly cosmopolitan, and Knowlton tells us that of the North American species, excluding the cycad trunks (Fig. 318), about half are also found in Japan, Manchuria, Siberia, Arctic Alaska, Spitzbergen, Scandinavia, or England. What is even more remarkable, the Jurassic plants collected by the Shackleton Expedition in Louis Philippe Land, to the south of Cape Horn, in 63° south latitude, are practically the same as those of Yorkshire, England.

The flora of the Jurassic, while in the main a continuation of that of the late Triassic (see Fig. 458), and consisting of rushes or Equisetales, modern herbaceous and tree ferns, cycads, ginkgos, and modern conifers, the descendants of which are now found mainly in southern lands, also shows the incoming of a number of more modern types in these groups. The cycads were of course abundant and diversified, so much so, in fact, that the Jurassic is often called the *Age of Cycads*. In some places, as in the state of Oaxaca, Mexico, the fossil cycads make up 72 per cent of the flora.

Medieval Insects. — While many of the stocks of modern insects are thought to have had their rise in the Triassic, this conclusion is attained only from a study of the Jurassic forms, of which about one thousand species are known, against twenty-seven in the older period. In the Jurassic the insects began to feed on parts of the plants, but probably few as yet visited the inconspicuous flowers of that time for their small amounts of honey. There were as yet no butterflies, but the caddis-flies, the larva of which is known as the caddis-worm, the scorpion-flies, dragon-flies, and beetles were abundant. Other kinds of insects known from this time are the cicadas, grasshoppers, locusts, cockroaches, ants, and termites.

Land Animals. — In general it may be said that the reptiles attained a higher and more diversified development than in the Triassic. True lizards appeared with the Jurassic, and the turtles were then abundant and world-wide in distribution. Although dinosaurs must have abounded in America, none are yet known, since those that were formerly assigned to this period (Morrison) are now regarded by many geologists as of Comanchian age.

One of the most remarkable groups of Jurassic carnivorous reptiles was that of the flying dragons or pterosaurs (from the Greek words meaning *wing-lizard*, see Fig. 466). They appeared late in the Triassic and were characteristic and important in the Jurassic, ranging in size from that of a crow to 3 feet across the wings. The

Fig. 466. — Jurassic "dragon of the air," or pterosaur (*Rhamphorhynchus phyllurus*), × ⅛. After O. C. Marsh.

fore limbs of these animals were modified into wings, as in the bats of to-day, and like them they actually flew. The head was relatively large, but very lightly constructed, and set at right angles with the neck, as in birds.

The joints of the external finger of the hand were much thickened and elongated, this finger being longer than the body and legs together. A membrane devoid of scales and feathers was stretched between the elongated finger on one side and the body and leg on the other, thus forming the wing. The legs, like those of bats, were small and weak, and the tail was very short in some species and very long in others, bearing in one form at least an oar-like expansion at the tip. They were carnivorous animals, feeding in the main on fishes, small reptiles and crustacea. Like most reptiles they probably laid eggs, and may have been warm-blooded.

Birds. — Birds are warm-blooded, very specialized descendants of dinosaur ancestors. They appear as fossils for the first time in the Upper Jurassic and represent one of the most remarkable advances which the life of this period has to show. As yet, only a single kind of Jurassic bird has been found, and this is from the

Fig. 467. — Restoration of the most ancient known bird, *Archæopteryx macrura*, feeding on the fruit of a cycad. After Gerhard Heilmann.

highest division, near Solenhofen, Germany. This bird, about the size of a large pigeon, is called *Archæopteryx* (Greek for *ancient wing*), and has many points of resemblance to the reptiles, and many characters which recur only in the embryos of modern birds (see Figs. 467, 468).

Fig. 468. — Head of *Archæopteryx*, as restored by Heilmann.

The peculiarities which strike one at the first glance are in the head and tail; there was no horny beak, but the jaws were set with a row of small teeth, while the tail was very long and, in shape like the leaf of a date palm, composed of separate vertebræ, and with a pair of quill-feathers attached to each joint. The wing was constructed on the same plan as that of a modern bird, but was decidedly more primitive. The four fingers were all free (in recent birds two of the three fingers are fused together); they had the same number of joints as in the lizards and were all provided with claws. The plumage was thoroughly birdlike in character, but was peculiar in the presence of quill-feathers on the legs, and apparently also in the absence of contour feathers from the head, neck, and much of the body, leaving those parts naked. This very extraordinary creature was, then, a true bird, but had retained many features of its reptilian ancestry. (Scott.)

Reptiles of the Seas. — The *Ichthyosauria* (Greek for *fish-lizard*) were a highly characteristic group, for though they appeared in the Triassic and continued into the Comanchian, the Jurassic, and especially the Lower Jurassic, was the time of their principal expansion (Fig. 469). Certain localities in the Lias of England and Germany have furnished an extraordinary number of skeletons, some of the specimens preserving the impressions of the outlines of the body and limbs and showing recognizably the nature of the skin. The ichthyosaurs, Scott tells us, were entirely marine in their habits and preyed upon fishes; their limbs were converted into swimming paddles, and there was a dorsal fin and a large tail-fin, the latter being the principal organ of propulsion. The muzzle was drawn out into an elongated slender snout, armed with numerous sharp teeth, which were set in a continuous groove, instead of in separate sockets. The neck was very short and the skin smooth. In length, these reptiles sometimes exceeded 25 feet, and in appearance they must have been very like the modern porpoises and dolphins. The resemblance, however, is wholly superficial, since porpoises and dolphins are warm-blooded mammals.

Another group of carnivorous marine reptiles was that of the

Plesiosauria (Greek for *near-lizard*), which appeared in the Triassic and culminated in the Jurassic, and which formed a curious contrast to the ichthyosaurs (Fig. 471). In the typical genus, *Plesio-*

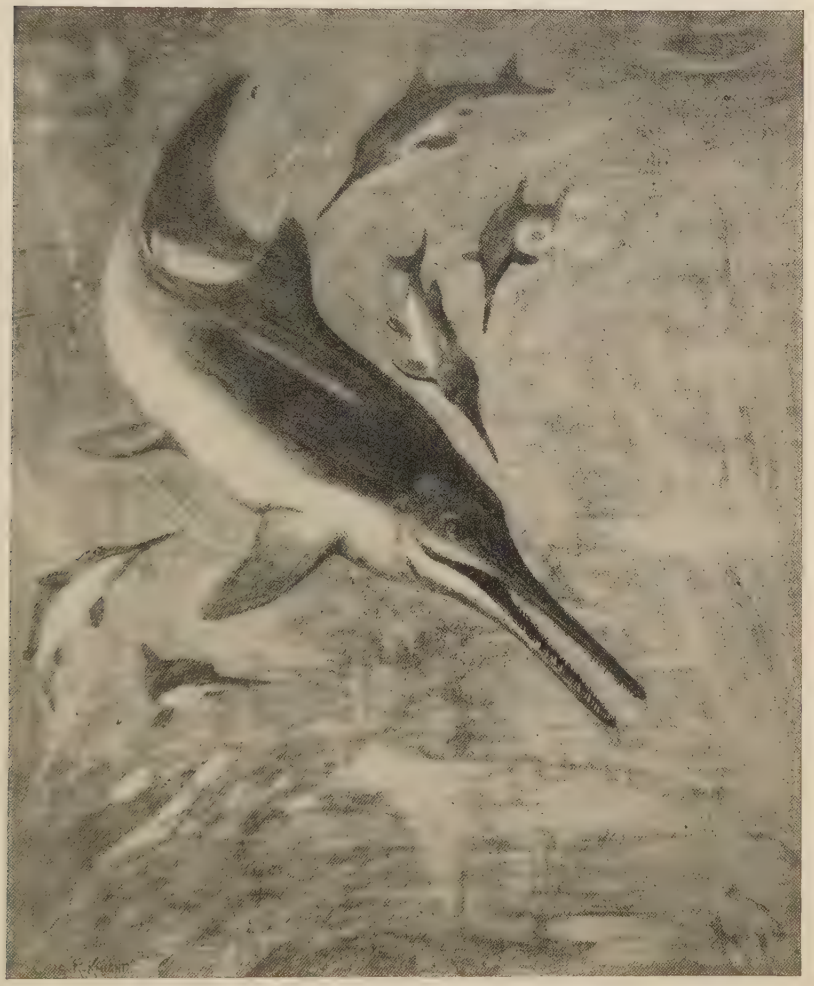


Fig. 469. — Restoration of a Jurassic marine fish-lizard (*Ichthyosaurus*). Mother with brood of young. After C. R. Knight and H. F. Osborn. Copyright, American Museum of Natural History.

saurus, the head was relatively very small, and the jaws were provided with large, sharp teeth, set in distinct sockets. The neck was exceedingly long, slender, and serpent-like, and was marked off distinctly from the small, box-like body. The swimming paddles

were much larger than in the ichthyosaurs and probably had more to do with locomotion. The Jurassic species of *Plesiosaurus* did not much exceed a length of 20 feet.

Crocodiles swarmed in the seas and rivers of Jurassic time. In appearance these reptiles resembled the modern gavial of India and had a similar elongate and slender snout. The fore legs were much smaller than the hind, and the animals were probably less exclusively aquatic in their habits than the present-day crocodiles and alligators.

Fishes. — Nearly all of the Paleozoic fishes were absent in the Jurassic, excepting the ganoids and lung-fishes. The former were now at their highest development, not only in the fresh waters, but in the seas as well. Some of these Jurassic forms were evidently the forerunners of modern sturgeons.

The sharks of the seas had attained their modern development, and in the Jurassic the flat fishes known as rays made their appearance.

Marine Invertebrates. — The seas of Jurassic time were replete with invertebrate life. This statement, however, is based on the development of Jurassic rocks in Europe and Asia, where about twenty-five forms are known for each one in America (15,000: 600). As is pointed out elsewhere in this chapter, this dearth of marine

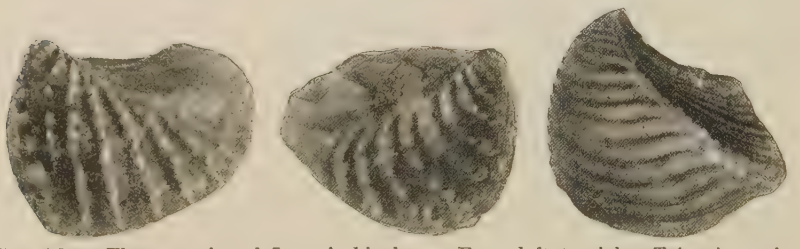


Fig. 470. — Three species of Jurassic bivalves. From left to right, *Trigonia navis*, *T. clavellata*, *T. costata*.

life in America is due mainly to the absence of marine strata and to the fact that when such are present the deposits are not those of normal marine conditions.

The Jurassic rocks abound in microscopic Protozoa of the classes Foraminifera and Radiolaria (described in Chapter L). In the Alps, beds of red flints and jaspery slates (known as radiolarite) are largely made up of radiolarians. Sponges are locally very common and well preserved, and in places make up thick reef limestones. Other reefs are made of modern corals (Hexacoralla) and these are of very wide distribution in the Middle and early Upper Jurassic (see Fig. 465). Crinids are at times common and in the Lower Jurassic are found the largest forms that ever lived, the pentacrinids, which grew to 50 feet in height, with a crown a yard

Fig. 471. — Restoration of Jurassic reptiles known as plesiosaurs, from Germany. In the rear are ichthyosaurs. From Fraas's Guide to the Stuttgart Museum.

in length and width. Since Jurassic times the crinids have played no important rôle in the seas. Sea-urchins of modern types are also common and here appear the so-called irregular urchins (Fig. 393) that later on gave rise to heart-urchins and sand-dollars. The starfishes and brittle-stars are not common, and those present are of modern types.

Brachiopods are still plentiful, but not in great variety, except in the rhynchonellid and terebratulid families. Almost all of the Palæozoic forms vanish with the Jurassic. On the other hand, the rocks of Jurassic time abound in molluscs, which are prophetic of the rise of modern forms. The seas were full of small and large bivalves, some of which were not only very ornate but characteristic of this time (*Trigonia*, Fig. 470, and plicate oysters, Fig. 472). Gastropods are also common and the siphonate forms are the most valuable for historical purposes (see Pl. 37). The most characteristic shell-fish of the Jurassic, however, were the ammonids, to be described in the next chapter. The crustaceans, usually rare as fossils, are represented by many kinds of lobsters in the Upper Jurassic about Solenhofen, Germany, due to unusually favorable conditions of preservation. The ancestors of the modern crabs also appear here (Fig. 474).

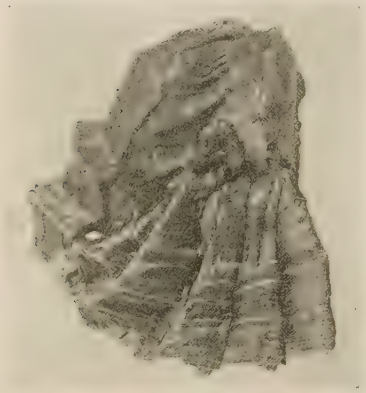


Fig. 472. — Plicated oyster of the Jurassic (*Ostrea marshi*).

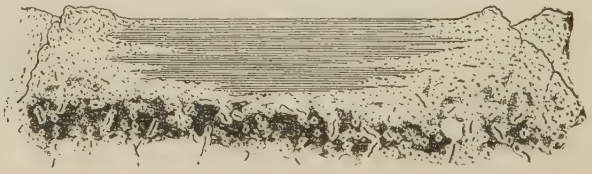


Fig. 473. — Profile through reef-dolomite and lithographic thin-bedded limestone of a Jurassic atoll near Solenhofen, Germany. After J. Walther.

Life of a Jurassic Atoll. — In the region about Solenhofen, during the Upper Jurassic, a series of reefs were built in a more or less circular form by sponges and corals. On the outside of the atolls the deposits are in the main thick series of dolomites and magnesian limestone in heavy beds, while the area inside, never over 75 feet thick, consists of thin-bedded, platy limestone of very fine grain and

of extraordinarily uniform character, representing a limy mud flat, in part permanently under water, and in part flooded twice daily by the tides (Fig. 473). These deposits are the lithographic limestones, which are used throughout the world for the engraving and etching of the monotone and colored prints known as lithographs.

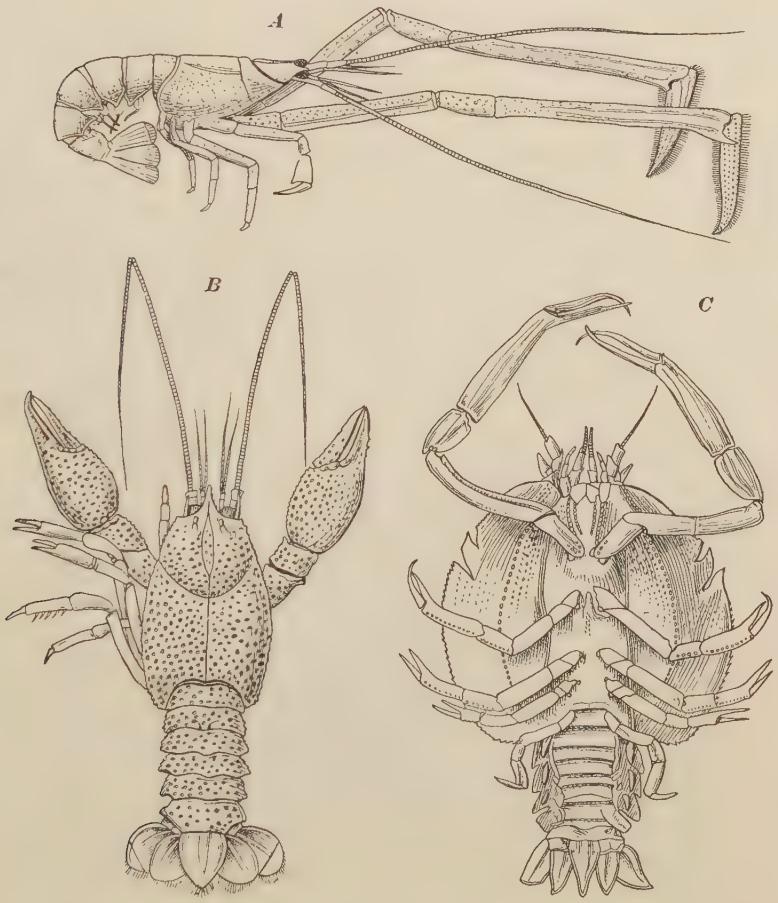


Fig. 474. — Lobsters and crabs from the Jurassic atoll limestones. *A*, *Mecochirus; B*, *Eryma; C*, *Eryon*. After Oppel, from Neumayr's *Erdgeschichte*.

In these platy limestones is found a most wonderful assemblage of animals of the sea and of the land, consisting of forms almost unknown elsewhere. Walther in 1904 monographed this region and its fauna, which amounts to 450 species. The life of the land is represented by a very few plants, more than 100 species of insects, probably blown upon the mud flats from the lands near by, 6 turtles, 9 crocodiles, 1 dinosaur with young, 29 flying reptiles (Pterosauria, Fig. 466), 3 other kinds of reptiles, and the oldest known bird (Fig. 467). Of fresh-water

animals there are none. Of marine fishes, mainly ganoids, there are 143 species, and of crustaceans, mainly of the lobster type (Decapoda, Fig. 474), 71 forms, of ammonids 7, annelids 13, crinids (comatulids) 4, some starfishes, brittle-stars and echinids, and 8 medusæ. All the other types of bottom-living invertebrates, mainly molluscs, are represented by but 40 species that were more or less accidentally drifted into the atoll.

CHAPTER XLVIII

AMMONITES AND BELEMNITES, THE DOMINANT ANIMALS OF MESOZOIC SEAS

Ammonites

General Characters. — The Mesozoic seas were characterized by an abundance of the shelled cephalopods known as ammonids (see Pl. 30). These beautiful coiled shells, relatives of the nautilids, were exceedingly varied in size, shape, ornamentation, and in the character of their septa (the transverse plates dividing the shell cavity into chambers), and more than six thousand forms have been described by paleontologists. Probably the average size would be between 3 and 4 inches, although they may range up to

Fig. 475. — Jurassic ammonite with the animal restored. Rostrum shown in right-hand figure. From Fraas's Guide to the Stuttgart Museum.

diameters of 7 feet, and if the coiled tube in such large ones were straightened out, the length would be between 20 and 35 feet. The ammonids therefore exceeded the Paleozoic nautilids as much in size as they did in specific differentiation. They appear to have been more active animals and better swimmers than the nautilids and therefore crawled less over the bottom of the sea. If they

were good swimmers, they must also have had a functional hyponome (see page 620 and Fig. 379) like the nautilids, but this conclusion is rejected by many paleontologists. The belief that they did swim well is deduced from the nature of the very thin shells, the wide distribution of some of the species, and the small depth, or narrowness, of the coiled cones (see Fig. 475). This statement applies to practically all the tubes that are wound in a plane like a watch spring, but where the shells are spiral, more or less unwound, or straight, they are thicker and the animals are believed to have crawled rather than to have swum (see Pl. 37, Fig. 16). Before proceeding further, the student should refresh his memory by reading what has been said about nautilids on page 619.

History of the Term. — The word *ammonite* goes back to 1732 and the days when fossils were regarded as minerals, as is indicated by the ending *ite*. The shells were so named because of a fancied resemblance to the horns of rams, pictured as one of the attributes of the Egyptian deity Ammon. In India these fossils are current as an article of trade, and they are used throughout that country in certain religious rites.

Comparison with Nautilids. — In many ways the shells of ammonids are like those of the pearly nautilus, but they differ therefrom radically in a number of respects. They are nearly always more ornate, narrower or less deep, and are often distinctly *keeled* along the center of the outer whorls. Further, the mouth of the shells often has lobed extensions on the sides (lappets), and in general there is a median keel that may be drawn out into a sharp point, the rostrum (see Fig. 475). On the other hand, the siphuncle in nautilids is near the center of the septa, but in the ammonids it is always placed near or in contact with the cone on its outer or ventral side (also called venter). In nautilids the mouth of the shell is never closed by an operculum, but in the goniatids and ammonids it probably was closed in most forms by a covering when the animal was at rest. This covering, when thin and made of chitin, is known as the *anaptychus*, but when thick and consisting of carbonate of lime in two hinged pieces is called the *aptychus*.

Nature of Septa. — However, all of these differences, while of importance, are not so valuable in classification as is the nature of the septa (see page 620). In the nautilids these partitions in the chambered shell are simple and more or less concave; in the ammonids, they are simple only in the central part, and each septum becomes more and more fluted or wavy toward its junction with the outer shell (Pl. 30, Figs. 10 and 14). When the outer shell is

absent, as is so often the case in these fossils, the *suture line*, or edge of the septa, is always seen as a wavy line with a distinct pattern, and this pattern also becomes more and more complex with age (see Pl. 30, Fig. 11). It is this complicated suture line, with its intricate *lobes* (inwardly directed) and *saddles* (curved toward the mouth of the shell), that makes these fossils so valuable in deciphering the chronology of Mesozoic time, since it indicates a progressive evolution that has been determined from the sequence of the strata, checked by the individual's growth or ontogeny.

The question is often asked: Why did these animals develop so complicated a type of septum? Among the nautilids we rarely see any approach to the lobed type of septum and here the living chamber is not only variously deep but wide as well. In other words, the ventral side of the cone is rounded and broad, and the shells are usually considerably deeper than those of the ammonids. Therefore the side muscles holding the shell to the animal not only have a greater holding surface in the nautilids, but, what is more important, the cone is more or less round, and therefore rests more uniformly on all parts of the animal, while in the ammonids the shells are lenticular and are therefore more easily turned to one side when in motion through the resisting water. It was probably the narrowness and the appressed nature of the shells that led to lobation of the septa, through the necessity of increasing the holding power of the animal on the shell. In any event, lobed septa are seen only in lenticular shells of cephalopods (nautilids, goniatids, ammonids).

Evolution. — The deep-shelled nautilids late in the Silurian gave rise to small and narrow-shelled *goniatids* with sparingly lobed septa. In most of the goniatids of the Devonian (Pl. 18, Figs. 1–6), the suture line of the lobes and saddles terminates sharply, but in the Mississippian the majority of the species not only have more lobes and saddles, but these are nearly all rounded. Thus we see a gradual change in the narrow-shelled cephalopods, beginning as true nautilids, and passing into various stocks of more or less narrow-shelled goniatids that finally gave rise in the Carboniferous to many lines of evolution among the primitive ammonids, resulting in the establishment of the latter in the warmer Permian waters of the Tethyian mediterranean (Fig. 433). The greatest variation among them took place during late Permian and early Triassic time. At the close of the Triassic they mostly disappeared, probably due to a colder climate and oceanic water. In the Jurassic, there was another rapid evolution out of two or three stocks only and the zenith of development was attained at this time. The waning of the ammonids began in the Comanchian, and during the Cretaceous the stocks showed little of their old virility and far more of old age expression, as seen in the uncoiling of the cones and in

the lack of evolution (see Fig. 495). Their complete extinction came at the close of the Cretaceous during the critical time of the Laramide Revolution.

Belemnites or Ink-fishes

General Description. — In the Mesozoic we likewise see the rise of the belemnites, the ancestors of the cuttle-fishes (also known as cuttles or squids, Fig. 476). The word *belemnite* comes from the Greek name for *dart*, the fossils being regarded at one time as the thunder bolts of Thor, the god of thunder (Fig. 477 *A*). The belemnids were very active, highly carnivorous cephalopods, which fed on fish, crabs and molluscs. They had large and fully developed eyes, were devoid of external shells, and because they had but two internal gill-plumes, the name Dibranchiata has been given to them. They had ten arms, possibly eight short and two long protrusible ones, as in the living squids (Fig. 476). In the Mesozoic these arms were often provided on their inner side with bent chitinous hooks for holding, and, more rarely, with holding suckers. Later the suckers became the dominant type. At first the belemnids had a heavy internal skeleton, but during the Mesozoic, out of the belemnid stock arose the squids, animals that continued as geologic time went on to lose more and more of the ancestral skeleton, though there is still left a vestige of it in all of the living forms.

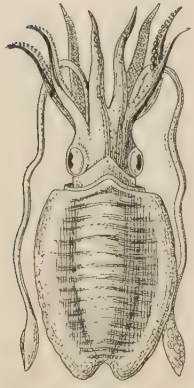


Fig. 476. — Living European ink-fish or sepia (*Sepia officinalis*), as seen from the upper side, much reduced. Note suckers on inner sides of arms. From Woodward's *Life of the Mollusca*.

Ink-sac. — All Dibranchiata are provided with an internal ink-sac containing sepia, a brown-black fluid that mixes readily with the sea-water; this the animals squirt in front of them when in danger and then make their escape backward away from the defensive screen of colored water. The sepia of artists is a pigment made from this substance. Like the other cephalopods, the dibranchiates are provided with a siphon through which water is shot forward, propelling the animal backward. They can also swim by the aid of their side fins.

Nature of Skeleton. — The belemnids originated in the early Triassic (Pl. 30, Fig. 3) out of the Paleozoic orthocerids (Pl. 5, Fig. 17), in that the animals, as it were, made their way more and more out of the external shells and enveloped these by their mantles in

such a manner that they became internal skeletons — an internal pedigree indicating their lineage (see Fig. 477). Among the fossils the part that is usually preserved is called the *guard*, a more or less cigar-shaped, solid, calcareous body, pointed at one end, with a deep circular pit at the other. These guards are sometimes as long as 2 feet and as thick as 4 inches. In the pit of the guards and extending beyond them occurs the chambered and siphunculate *phragmacone*, the vestige of their orthocerid ancestors. This extends forward on the dorsal side into a more or less long piece, either of lime or of chitin, which is known as the *proostracum* (see Fig. 477 *B*). The belemnids are quite characteristic of the Mesozoic, are fine stratigraphic guides, and there are about four hundred kinds known.

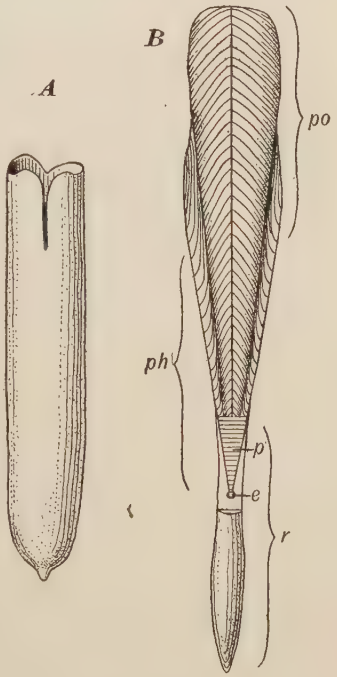


Fig. 477. — Internal skeletons of Mesozoic belemnids. *A*, guard, the commonly preserved part of a Cretaceous form (*Actinocamax quadratus*), about nat. size. *B*, entire skeleton and pen restored. From Steinmann's *Einführung in die Paläontologie*. *e*, embryonic or first shell; *p*, chambered phragmacone (vestige of an orthocer-acone) passing upward into the limy or chitinous phragmacone (*ph*); *po*, proostracum; *r*, solid guard or rostrum cut to show chambered phragmacone.

The true squids of the Mesozoic retained only the proostracum and a completely modified remnant of the phragmacone, which together made a thick and wide, but meshy and therefore light, secretion of carbonate of lime, known as the cuttle-bone. Over the proostracum and projecting beyond it toward the head lay the *pen*, so called because it looks like a quill pen, made of chitin. In some of the living squids or cuttles there is left only the pen. In the Upper Jurassic of Solenhofen are found cuttle-bones fully 2 feet long, indicating animals with a probable body length of 6 to 8 feet; in the present seas live the greatest giants, whose bodies are 18 feet long, with the two protrusible arms attaining a length of 30 feet when fully extended.

CHAPTER XLIX

THE COMANCHIAN PERIOD, THE TIME OF GIGANTIC SAUROPODA

History of the Period. — In the early part of the past century the European geologists regarded the rocks overlying the Jurassic as making up the Cretaceous system. At first, this latter system included only deposits of chalk, but gradually more and more formations, of other materials, were added because the fossils clearly linked them together. In this way the Cretaceous came to embrace so great a mass of heterogeneous strata that with the increase of knowledge it became necessary to separate the formations into Lower Cretaceous and Upper Cretaceous divisions. This usage is still generally accepted in Europe, though as long ago as 1887 Neumayr said that if this classification had originated elsewhere than in England, we would then have been regarding the Cretaceous formations as making up two easily separable systems of rocks. In England, the physical characters of the uppermost Lower Cretaceous and the older beds of the Upper Cretaceous are so much alike that no break in sedimentation is readily seen, but on the Continent the separation can everywhere be easily made out. Moreover, the Lower Cretaceous was a rather restricted marine transgression, with widely distributed continental deposits (Wealden), while the sediments of the Upper Cretaceous were almost wholly of marine character and probably record the most marked spreading of the oceans in all geologic time. From these facts we see that the earth underwent two cycles of diastrophism during the " Cretaceous," and the physical evidence is at hand to classify its formations into two systems that in America have recently been called the Comanchian and Cretaceous periods.

It should be stated here that stratigraphers are not yet agreed that Comanchian as defined in this book is a natural system of rocks and represents a period of time that is also recognizable in European rocks and fossils. Comanche series (see below) is clearly a good provincial term and represents a unit of geologic time that is typically developed in the southwestern Gulf States and northern Mexico and from here north to Kansas and Colorado. European geologists say, and perhaps correctly, that the Washita group is Cenomanian in age and hence is not of Lower Cretaceous time, but as it is very closely connected with the rest of the Comanche in Texas, it cannot be separated from the latter.

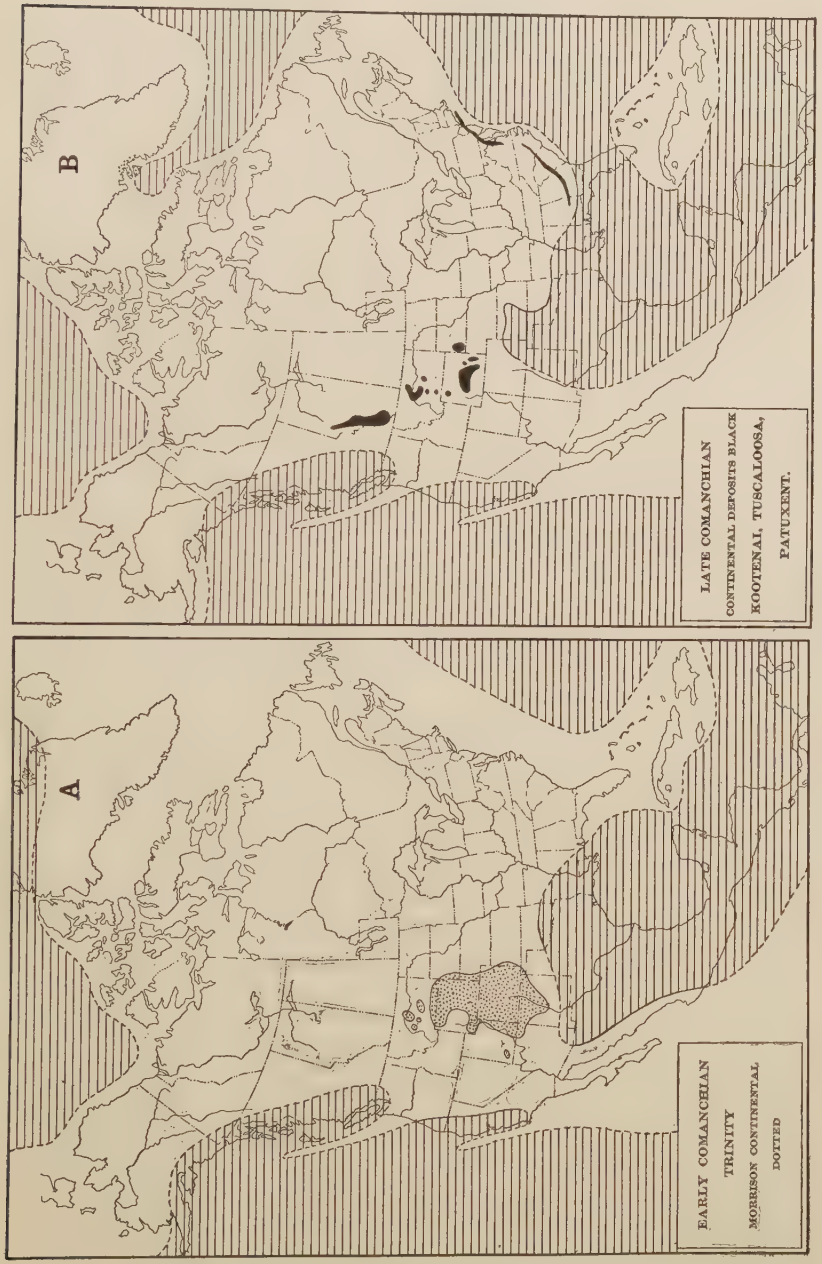


Plate 35. — Comanchian paleogeography.

Comanche Series of Texas. — Robert T. Hill a number of years ago made a special study of the "Lower Cretaceous" strata in Texas, and in 1887 he proposed for them the name *Comanche series*, because they occur in the home of the Comanche Indians. His ideas gradually prevailed and the rocks and their fossils are now being more and more widely recognized as representing a diastrophic cycle of sedimentation and water movement, the Comanchian period. The succession is best known in central Texas, where there is an abundance of fossils in a thickness of 1500 feet. Hill also divided the system into three series, calling the lower *Trinity*, the middle *Fredericksburg*, and the upper *Washita*.

In central Mexico, where these divisions are not yet clearly made out, the geologists adopt a two-fold separation into Eocretaceous (Lower) and Mesocretaceous (Middle). An older American term, however, is *Shastan*, based on the Shasta group of California and defined by Gabb and Whitney in 1869. This development is wholly distinct, faunally and lithologically, from the Comanche of Texas. They correctly recognized that the group "contains fossils seemingly representing ages from the Gault to the Neocomian, inclusive."

Lower Cretaceous of Europe. — In Europe the Lower Cretaceous appears in two phases: (1) a northern shallow-water, cooler, and more or less brackish one, terminating northward and westward in continental beds (the Wealden); and (2) a southern normal, marine, and warmer water phase that is of wide distribution in the area of the Tethyian mediterranean.

American Phases of Lower Cretaceous. — In America a continental phase occurs to a limited extent along the borders of the Atlantic (Potomac), and extensively in the Rocky Mountains (Morrison and Kootenai). The marine development is of two faunal provinces, (1) a Pacific overlap (Shastan), and (2) a Gulf of Mexico extension widely over Mexico, and in the United States from Texas to Kansas (Comanchian).

The Comanchian deposits may be arranged as follows:

Marine Phase of Europe			American Pacific		Gulf of Mexico		American Atlantic
Gault-Albian			Horse-town	Shastan	Washita	Comanchian	Patapsco
Lower Green-sand	Aptian				Frederi-cksburg		Large break
	Barrémian-Urgonian		Knox-ville				Arundel
Hauterivian	Hils or Neocomian	The fresh-water Wealden			Trinity		Break
Valanginian							Patuxent
							Break

Comanchian of Western America

Pacific or Shastan Marine Overlap. — The Sierra Nevada Disturbance at the close of the Jurassic gave birth to a structural valley, now the Great Valley of California, lying between the Coast Range and the Sierra Nevadas. Into this subsiding trough the Shastan sea (Le Conte) spread, while in British Columbia and Alaska the Pacific Ocean gradually encroached more and more widely as a marginal overlap or shelf sea (see Pl. 35). The sediments poured into these seas were coarse-grained and were delivered to them by the rivers flowing out of the highlands to the eastward.

The deposits are essentially sandy shales with thin bands of sandstone, local conglomerates, and rarely thin limestones. The thickness in northern California appears to be between 9000 and 10,000 feet, of which about one third is of Knoxville time, while the remainder is of Horsetown time.

The maximum thickness of the Knoxville in northern California is about 20,000 feet, according to Diller and Stanton. Of this extraordinary thickness, about 16,000 to 17,000 feet is in general poor in fossils but occasionally there are beds replete with *Aucella* (*A. piochii*), a bivalve which is of boreal origin (see Fig. 464). The associated floras, however, Knowlton unhesitatingly refers to the Jurassic. (See page 872.)

The Shastan overlap is also known in northern Washington and along the Canadian and Alaskan coasts. The deposits of these areas are dominantly sandstones with sandy shales, and in most places include considerable thicknesses of volcanic material (from a few hundred feet up to 3350), lavas, tuffs, and ash beds. In the Queen Charlotte Islands, where these strata have coal beds, the depth is estimated at 9500 feet, and elsewhere, although somewhat less, the thicknesses are rarely as low as 2000 feet, but in places the Comanchian strata were entirely removed during the intervals of erosion. Finally, along the Arctic coast of Alaska there also appear to be Comanchian unfossiliferous strata that at Cape Lisburne are over 5000 feet thick.

The Comanchian sands and muds of the Pacific in most places overlap unconformably the older and often metamorphosed formations. This unconformity is often marked, as in the Klamath Mountains and the Coast Range, or is of the erosional type. However, there are also disconformable contacts. The faunas are of the Indo-Pacific realm and are remarkably distinct throughout from those of the Comanchian seas, a condition indicating that the two provinces were completely separated from one another by a land barrier, the western Mexican mass.

The floras of the higher Knoxville (thirty-three species) and of the Horsetown (nineteen) were of the early Comanchian type (Lower Potomac), and flowering plants of the modern types (Angiosperms) are wholly unknown in them. In the Upper Knoxville (4000 feet) the small marine molluscan fauna was still of boreal origin (*Aucella crassicollis* biota). A marked change in the faunas took place in Horsetown time, as the life of the seas then had a Mediterranean (Tethys of India, also of Japan) aspect, a migration that made its appearance earliest in California and Oregon. It, too, was a molluscan fauna of about eighty species, of which over thirty forms were ammonids. This assemblage is known as the Indo-Pacific fauna. (Stanton.)

Fig. 478. — Folded Comanchian limestones in Saltillo Canyon, northern Mexico. Photograph by C. B. Waite.

Mexican or Comanchian Marine Overlap. — From southern Arkansas across central Texas into southeastern Arizona, and thence across almost all of Mexico to the Isthmus of Tehuantepec, are found limestones and marls that are of Comanchian age. These are the deposits of the most extensive inundation by the oceans which befell Mexico and which was greatest here in Middle Comanchian time. Moreover, they form the greatest area of Comanchian rocks and faunas in North America (see Pl. 35). Aguilera of the Mexican Survey states that these deposits make up the main mass of the limestones of the folded mountains of Mexico and in this respect contrast decidedly with the sandy nature of the Shastan sediments. The average thickness is between 3300 (Mazapil) and

4000 (Vera Cruz) feet, and almost all of it is limestone (see Fig. 478). At Bisbee, Arizona, the thickness is about 4700 feet, beginning with conglomerates, thence passing into sandstones, shales and limestones (650 feet), and ending with red shales and variegated sandstones. In northwestern Mexico, about Hermosillo, occurs a very similar succession of strata that are nearly 3000 feet thick and bear coal in the upper beds, according to Dumble. In central Texas, the typical area for Comanchian strata, the thickness is 1500 feet, consisting of limestone, some chalk, but mainly marls and shales, thinning out to a few hundred feet of sands and marls in Arkansas.

Great Plains Extension of the Comanchian Sea. — Late in Comanchian time (Washita) the sea of the Texan area spread northward across New Mexico and Oklahoma, to the south and west of the Quachita Mountains, into central eastern Kansas, southeastern

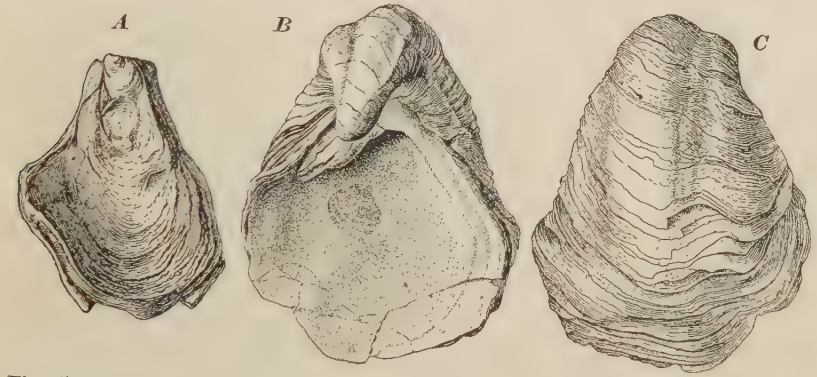


Fig. 479. — Oyster-like shells of the Comanche of Texas (*Gryphæa mucronata*). After Hill and Vaughan, U. S. Geol. Surv. *A*, upper or free valve. *B* and *C*, lower or attached valves from the inside and outside.

Colorado, and possibly even into central Wyoming (see Pl. 35). This extension did not last long and its deposits consist in the main of muds and marls with sandstones in the west and southwest. The thicknesses are usually less than a few hundred feet, which in the north and east thin down to the vanishing point. The faunas here are always limited but include oyster-like shells (*Gryphæa*, Fig. 479), which often abound in great quantities; evidently the waters were shallow, turbid, and somewhat freshened by the rivers flowing into this extensive bay.

The flora of early Comanchian time (Trinity), as found in Texas, was still Jurassic in character. On the other hand, the plants from the top of the Comanchian (Washita) found in Kansas show that a great change had come over the

forest floras, as flowering plants (Angiosperms) were now present in great numbers and in forms like those of the succeeding Cretaceous.

The marine invertebrate faunas were large and varied, consisting of about four hundred species, and were of normal marine character in Mexico and throughout Texas, becoming less so northward into Kansas and Colorado. The species were essentially of molluscs, with the ammonids making up about one third of the assemblages in Mexico and Texas, though farther north these latter are lacking more and more. Among the bivalves the most characteristic forms were the chamids *Requienia* and *Monopleura*, and the rudistids *Radiolites*, etc. (Fig. 480).

The Comanchian faunas are also widely distributed throughout Central America, and in the high Andes in northwestern and western South America assemblages of these animals are present, though much modified by local evolution. In a general way it may be said that the Comanchian faunas were largely of mediterranean origin (Tethys), or rather that the Gulf of Mexico was in direct connection with the seas of Portugal, Spain, and southern France.

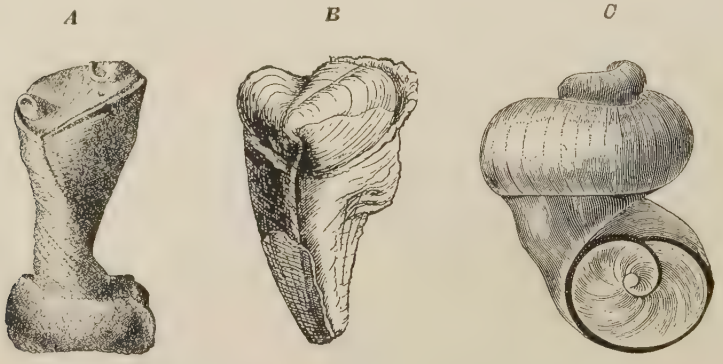


Fig. 480. — Much modified bivalves of the Comanchian. From C. A. White, U. S. Geol. Surv., and Kayser's *Lehrbuch der Geologie*. *A*, entire shell, from Texas, with the right valve attached (*Monopleura marcida*). *B*, a related form from Europe (*M. trilobita*). *C*, a form resembling a snail shell; here it is the large, spirally twisted, left valve that is attached (*Requienia ammonia*).

Morrison Continental Deposits. — Throughout the Great Plains country, from Montana south into New Mexico and overlying the marine Jurassic of the Logan sea, occur variegated green and red marls and shales with irregularly distributed beds of sandstone. They were first studied at Morrison near Denver, Colorado, and at Como Bluff near Medicine Bow, Wyoming. Over large areas the beds at first sight appear to be uniform in character, but seen in detail they vary considerably. The average thickness is about 200 feet, but locally it rises to over 400 feet. Because of the variability in the sediments from place to place, and especially because the strata yield in the main large dinosaurs (see Pl. 32, and Fig. 481), along with some archaic mammals (Fig. 484), fresh-water bivalves,

Fig. 481. — Carnivorous Comanchian (Morrison) dinosaur, *Ceratosaurus*. Length about 20 feet. Note tall tree-ferns in background, and low cycads in foreground, with an archaic mammal hiding among them. After J. Smit, from Knipe's *Nebula to Man*.

snail shells, and land plants, it is apparent that they are of fresh-water origin.

Hatcher held that the Morrison deposits were laid down over a comparatively low and level plain which was occupied by small lakes connected by an interlacing system of river channels. That there were swamps in which the great dinosaurs lived and that they were occasionally entombed therein is attested by the occurrence of more or less complete skeletons preserved in the rocks. Further, there are many fresh-water clams (unionids) and snails. The topography and climatic conditions of that time may be compared to those of the region about the lower reaches of the Amazon to-day.

Ever since 1877, when dinosaurs were recognized as such for the first time, the age of the Morrison has been under discussion. The difficulties in correlation are great because (1) the entombed animals, while abundant, are an isolated occurrence of land animals; and (2) the local stratigraphic position is not clearly defined in the geologic sequence. The strata lie disconformably upon the earliest Upper Jurassic deposits of the Logan sea, and in the same way usually below the Cretaceous (Dakota formation). In recent years, however, Lee and Stanton have shown that the Morrison in Oklahoma and southeastern Colorado actually lies directly beneath the Upper Comanchian (Washita). This then limits its age either to Upper Jurassic or to any Comanchian time older than the upper division or Washita. The only fossils of value in correlation are the dinosaurs, and these agree best with those of the English Wealden, which is now held to be of Lower Comanchian age.

Many years ago Marsh correlated the Morrison with the Wealden, but unfortunately the Europeans have not until recently agreed as to the period age of the latter. Twenty years ago the Wealden was almost always referred to the Upper Jurassic, and this conclusion was followed in America by Marsh and others. During the last decade, however, the tendency has been decidedly in favor of the reference of the Wealden to the older Comanchian, as was definitely proposed by Williston in 1909. Within the past few years giant dinosaurs have also been discovered in German East Africa, and as the containing strata have marine beds of late Jurassic and early Comanchian time associated with them, it is becoming clearer that the Morrison dinosaurs are in all probability likewise of Comanchian age. Moreover, the Morrison dinosaurs have been shown by Lull to agree best with those of the Arundel or middle formation of the Potomac deposits of the Atlantic slope, strata now definitely referred to the Comanchian.

While the Morrison is rich in vertebrate remains, there is little that is distinctively American. The fauna is a derivative of that of Europe, and we may agree with Williston's statement that during Morrison times there was freedom of migration between the eastern and western continents, so free that nothing distinctive of either region was developed through isolation.

Kootenai Continental Deposits. — In southern Alberta (Crowsnest Pass) and in southeastern British Columbia the Comanchian formations are of great thickness along the axis of the Rocky Mountains and are of fresh-water delta origin. These are the Kootenai deposits, chiefly sandstones and sandy shales of very varied texture and appearance, and with many beds of good coal. The maximum thickness of the Kootenai is 5300 feet, with twenty-two workable coal beds, known to extend over an area of nearly 3000 square miles. To the east the Kootenai thins rapidly to 200 feet, with two coal beds. In the Crowsnest area the coals aggregate 216 feet in thickness over an area of 230 square miles. Dowling estimates the coal of this region as equal to nearly 8,000,000,000 tons, and of this about 400,000,000 tons can be classed as anthracite.

The Kootenai is likewise present about Great Falls, Montana, where it is also coal-bearing, though the thickness here does not average over 450 feet, increasing to the west to 1500 feet. Other occurrences are in Wyoming, and in South Dakota (Lakota and Fuson formations), where about a thousand silicified cycad stumps have been found (one of which is illustrated in Fig. 318). The Kootenai in the Great Plains region directly overlies the Morrison.

Kootenai Flora. — The Kootenai fossils are essentially plants, a flora of eighty-six species being known. It is still of Jurassic character, as no flowering plants occur, the forms present consisting mainly of ferns (thirty-four species), cycads (nineteen), and conifers (twenty-five), as seen in Fig. 481. The flora is very similar to that in the Lower Potomac of the Atlantic border, twenty forms being common to the two areas. The botanists are disposed to regard the Kootenai flora as not younger than Middle Comanchian.

Comanchian of Eastern America

Potomac Continental Deposits. — In the chapter on Jurassic events it was stated that the mountains of eastern North America were reduced to a hilly country during that period. It is also true that the main drainage ways, the present large eastward flowing rivers, such as the Potomac, James, etc., were established at the same time. At the very close of the Jurassic it seems that the strand-line of the Atlantic Ocean had been extended further to the west (see page 846), and the continental shelf tilted a little more seaward. Thus the stream grades became more active, and the sediments eroded from the upwarped region were transported eastward to a lower level and spread as the Potomac formation upon the peneplained Piedmont Plateau (the Weverton peneplain) of ancient crystalline rocks. These deposits are now seen all the way from near Philadelphia, past Baltimore and Washington,

through Virginia into Georgia and Alabama (see Pl. 35). There are also scattering exposures in the islands off New England.

The Potomac formation is best developed in Maryland, where the thickness averages between 600 and 700 feet, and all the strata have a slight dip to the southeast, averaging about 40 feet to the mile. The rocks are exposed to the east of the elevated Triassic formations, and further eastward they gradually pass beneath the Cretaceous and Tertiary formations. The deposits consist chiefly of unconsolidated sandy clays, which at the base and in the west have greater amounts of sands and even conglomerates, and then the materials are usually arkosic or replete with fragmented feldspars. In addition, there may be considerable amounts of clay iron-stones (siderite) in the lower part (Arundel formation), and such have been mined in Maryland for more than a century. Because of the presence of these local deposits of iron, the formations assume a red color in weathering, and in the Upper Potomac the deposits are naturally variegated (Patapsco). The Lower Potomac begins with coarse materials highly variable from place to place (Patuxent formation), and finally in the Maryland region a restricted swamp land developed, as seen in the dark and carbonaceous deposits that are even locally lignitic (Arundel). Not only this, but the roots of the forests are still in the place of their origin, and it is in these swamps that the seven species of dinosaurs have been found which link this formation with the Morrison of the Great Plains country.

The Potomac formation is clearly divisible into a lower and an upper series by a marked erosional unconformity. Further, the floras are widely dissimilar in the two parts, since the Lower Potomac still retains the Jurassic aspect, while the Upper Potomac strongly introduces the Cretaceous assemblage of flowering plants or Angiosperms. The Lower Potomac is wholly of fresh-water origin, and was laid down in river valleys over the undulating Weverton peneplain, which had a relief of about 300 feet. On the other hand, the Potomac, although wholly devoid of marine fossils, may be of estuarine origin; that is, it may represent the fresh-water or landward part of the various deltas facing the Atlantic Ocean.

Western Greenland. — In central western Greenland occur Middle Comanchian sandstones alternating with dark shales which have locally very thin and poor beds of coal. This, the Kome formation, appears to be of fresh-water origin, and no marine fossil is known in it. The whole series is about 700 feet thick and reposes on a rather hilly floor of ancient (Proterozoic?) crystalline rocks (see Pl. 35). The flora is rich in ferns (forty species), cycads (eleven), and conifers (eighteen). Of flowering plants there are seven species.

Movements toward the Close of the Comanchian

Cordilleran Intermontane Disturbance (see Fig. 482). — Along the Pacific coast from San Luis Obispo County, California, northward far into Oregon (Coast Range Mountains in wider sense), there is evidence of crustal movement during the Comanchian. Anderson states that the Knoxville is everywhere in this area penetrated and disturbed by dikes and masses of serpentine and accompanying peridotites. Moreover, in the Coast Range of southern

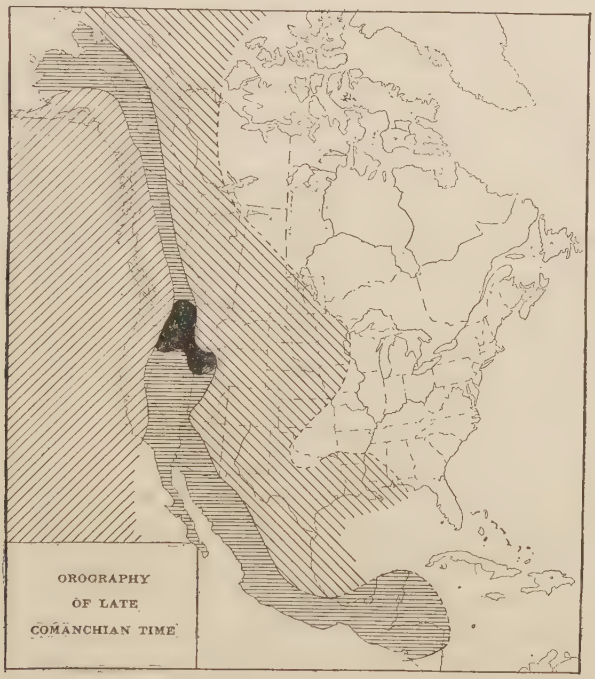


Fig. 482. — Outline map to show regions of elevation (horizontal shading and solid black), the formation of the Coloradoan geosyncline (right-hand diagonal lines), and the Pacific overlap. Generalized from Ransome, *Problems of American Geology*. The black area is that of the present Columbia River Plateau, the region of elevation to the north is known as the Northern Interior Plateaus, while that to the south is the Nevadan-Sonoran Region.

California, where these intruded rocks occur, the Horsetown strata are also absent, while the Cretaceous (Chico) unconformably overlies the older formations.

We have seen in previous chapters that the Pacific transgressed widely over the North American continent during the Triassic and again in the Jurassic, and that these overlaps occurred mainly in the northern or Canadian half of the continent. In the area of the

United States, however, uplift was making itself felt as early as Middle Triassic time, apparently bowing up a low arch in western Utah, eastern Nevada and throughout Idaho, forming together the Columbia River Plateau (black area of Fig. 482), and this arch persisted into late Jurassic time. At the close of the Jurassic, however, the Sierra Nevada folds were thrown up to the southwest of this uplift, and it was then incorporated into the area of the Sierra Nevada Disturbance. This late Jurassic movement also forever shut out the former wide extension of the Pacific, not only from the area of the United States, but from most of western North America as well.

If we next study the paleogeography of Cretaceous time it soon becomes apparent that the conditions of oceanic spreading had been further altered toward the close of the Comanchian, for subsequent to this period the Pacific shelf seas were narrow, and over what is now the site of the Rocky Mountains and far to the east in both Canada and the United States, a new inland sea appeared, the Coloradoan sea of Cretaceous time, extending from the Gulf of Mexico into the Arctic Ocean (Fig. 482). The barrier that kept these waters apart was the newly bowed-up land to the west of the present main Rocky Mountain ridges, the Cordilleran Intermontane Belt of Ransome, and this barrier continued to rise throughout all of Cretaceous time. We see here therefore the beginning of the process which made the Cordilleran Intermontane Belt of elevated plateaus extending from Arctic Alaska all the way into Central America, and it is for this reason that the movement may be called the *Cordilleran Intermontane Disturbance*.*

This disturbance also manifested itself in Mexico, for in late Comanchian time western Mexico and Central America into Nicaragua were elevated, shutting out here more or less of the earlier Gulf of Mexico overlap. When the seas of Cretaceous time returned, the life of the former Comanchian was completely changed, very few species being common to the two periods. In this we have the evidence of another break in the record, and one of considerable import for the separation of the Comanchian from the Cretaceous.

Disruption of Gondwana (see Fig. 434). — The great equatorial land across the Atlantic, which had so long united northern Africa to Brazil, was being disrupted by epeirogenic movements during Comanchian time and disappeared beneath the sea during the Cretaceous. The evidence for this is at hand toward the close of the former

* After the above was written a paper by Blackwelder appeared (1914), in which he called this movement the Oregonian Disturbance, but that term is not used here because of its too local significance.

period (Gault time), when the Atlantic began to encroach upon Brazil and equatorial West Africa at Angola. Further and more extensive overlaps were of Eocene time. We may therefore say that the present configuration of the Atlantic Ocean had its origin in late Comanchian time.

Potomac Disturbance. — At Washington the peneplain upon which the Potomac formations repose has a present slope of 112 feet per mile. The subsequent marine plain cut by the Cretaceous seas has a present grade of 33 feet per mile. Therefore these two successive planes are inclined to each other at an angle of 79 feet per mile, and indicate a raising, without folding, of the western Piedmont and Appalachian areas at least several hundred feet. (Barrell.)

Comanchian Climate

Floral Evidence. — On the basis of the floras, Berry holds that the Comanchian climate was considerably warmer than that of to-day, with much less change from season to season, and with a very long growing period. The rainfall was ample and fairly well distributed throughout the year. On the other hand, early in Comanchian time, the climate in polar lands was much cooler, for in King Charles Land (78° N.) Nathorst records trees more than 3 feet thick, having 210 annular rings, indicating that the difference between the seasons was pronounced.

Evidence of Land Animals. — In the temperate and tropical belts, the world in Comanchian time had the greatest of all land animals, the sauropod dinosaurs, reptiles attaining in the United States of America and in equatorial German East Africa a length of about 80 feet (see Pl. 32 and Fig. 481). These animals are thought to have lived in a warm climate in marshes covered with succulent plants along the margins of the continents and in the estuaries of the greater rivers.

Marine Evidence. — The marine faunas were not of warm waters in the far north, for no coral reefs are known there, but their distribution was then in higher latitudes than it is now. In general we may say, therefore, that after early Comanchian time the climate the world over was milder than it is at present and that it was warm temperate in character.

Life of the Comanchian

Floras. — The floras of Comanchian time are everywhere divisible into an early and late phase of development. The older ones, Berry tells us, are those of the Jurassic retained into Coman-

chian time, and they consist of ferns, cycads, and conifers (see Figs. 458 and 481). The rushes, however, had now dwindled into their present meagre representation, and the older Mesozoic ferns were giving way to the modern ones. Finally, in late Comanchian time, the cycads also began to wane, and their places were taken by the flowering plants or Angiosperms which were increasing in importance, for one third of these floras were of this type. They were the ancestors of the modern floras and prophetic of the rise of the living forests. In fact, at least three of the genera are still living (*Sassafras, Populus, Celastrophyllum*). Between three and four hundred species of Comanchian plants are known in America, and of these about two thirds are of the older development. Before the close of the Comanchian this early hardwood forest of modern appearance had spread to Alaska, Greenland, and Portugal, where elms, oaks, maples, and magnolias occurred, and later in the earliest Cretaceous times it had spread over the entire world.

Dinosaurs. — The reptiles probably attained the zenith of differentiation in the Comanchian, when the dinosaurs were present, not only in greatest variety but in greatest size as well. The most characteristic ones were the Sauropoda (*Brontosaurus* and *Diplodocus*), described at length in Chapter XLVI. The flesh-eating dinosaurs of the Comanchian were also large and terrible, but neither so large nor so ferocious as those of the next period (Fig. 481).

A most interesting burial of plant-feeding, bipedal, Lower Cretaceous dinosaurs has been found in the coal mines near Bernissart, Belgium. These are known as *Iguanodon* and the genus had long been known from single bones found in the Wealden of Europe. In taking out coal the miners came upon a river channel deposit cutting the coal, and in this, over 1000 feet beneath the surface, were twenty-two complete and seven incomplete animals (Fig. 483).

First Frogs.— It is interesting to note here that the oldest American frogs occur in the Comanchian (Morrison) strata of Wyoming (Marsh). They were very small animals and apparently not of much significance in the animal world of their time.

Archaic Mammals. — The rise of the reptilian mammals was noted in the Triassic chapter, and their fragmentary bones, especially teeth and lower jaws, are met with in the various deposits of the Mesozoic. In England they occur at the close of the Jurassic and in the Wealden, and in America in the Morrison (Fig. 484). Little is as yet known of these animals other than that the American and European species were very much alike, and that they belonged to the most primitive mammals, the Multituberculata. It is probable that the Mesozoic mammals were, in the main, egg layers.

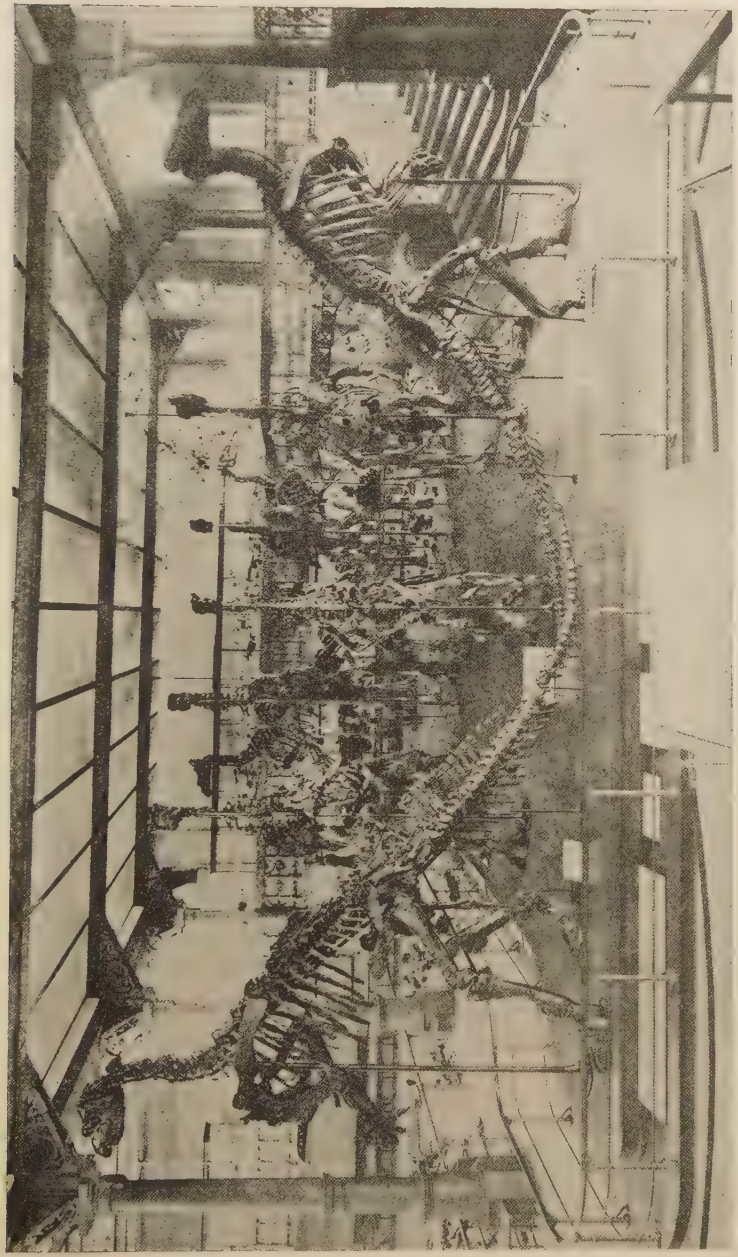


Fig. 483. — View in the Royal Museum at Brussels, Belgium, showing nine mounted skeletons of the herbivorous dinosaur *Iguanodon* (*I. bernissartensis*). From a photograph furnished by Professor Dollo.

Marine Life. — The ammonids were still plentiful, though less so than in the Jurassic, but in the Comanchian they began to show a great loss of vitality, in that but few new stocks arose, while old ones were evolving toward a loss of characters and an unwinding of the shell. For other details see Chapter XLVIII. The belemnids were still abundant and flourishing.

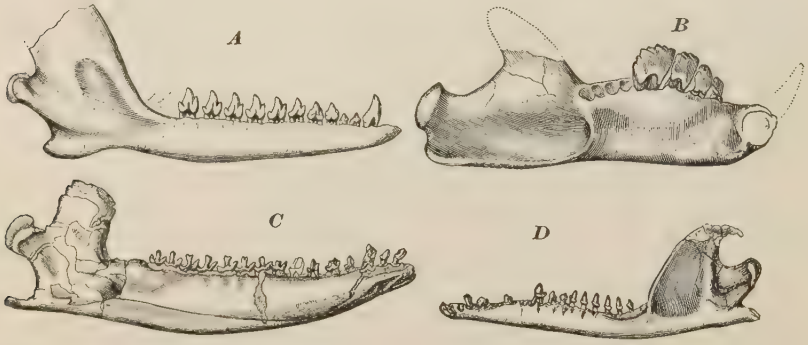


Fig. 484. — Archaic mammal jaws of the Comanchian (Morrison), somewhat enlarged. After O. C. Marsh. *A*, *Diplocynodon*. *B*, *Ctenacodon*. *C*, *Dryolestes*. *D*, *Stylacodon*.

The other invertebrate life of the sea was not very different from that of the Jurassic, and only a few of the more marked changes need be noted. The sea-urchins were very varied and prolific in the warmer seas, and the heart-urchins (irregular types) here and in the Cretaceous attained their climax of evolution (see Fig. 393). Among the bivalves, the ribbed oysters (Fig. 472) and the oyster-like Gryphæas (Fig. 479) were very abundant, especially in Tethys.

In the boreal seas, the aucellids (Fig. 464) were still plentiful, while in the equatorial waters of Europe, Texas, and Central America there arose remarkably aberrant stocks of bivalves, in which one valve cemented to some object, the shell growing upward into a short or long, twisted, thick cone, while the covering valve was either twisted or a thickened and simple hood (Fig. 480). These were the chamids and rudistids, which also continued into the Cretaceous and there gave rise to the caprinids and larger rudistids, shells that were veritable reef-builders.

CHAPTER L

CHALK AND ITS ORGANISMS

Chalk Deposits. — Although chalk is not the dominant material of the Cretaceous formations, and although it also occurs in the Comanchian, still, because of its conspicuous white color and its fine exposures in the cliffs along both sides of the English Channel (Anglo-Parisian basin), it gave the name to the great system of rocks following the Comanchian, the Cretaceous system (Latin *creta*, chalk).

For a long time chalk was believed to be a deep-sea deposit like the Globigerina oozes (see page 479) of the present abyssal oceans, but the kinds of fossils found in the chalks are indicative of shallow seas, and the formations are often accompanied by sands, while in closely adjacent areas the equivalent strata contain no chalk. In central Wyoming there is much white chalk in the Niobrara formation, but in the western part of that state deposits of the same age are sandy shales or sandstones. In central Kansas the so-called chalk deposits are in reality very fine yellow muds almost devoid of chalk organisms. In western Alabama the Selma chalk is 1000 feet thick, and laterally it changes into marls, clays, and sands. Accordingly it is now held that the chalks are organic accumulations made in the main by the calcareous skeletons of minute pelagic or bottom-living plants and animals, in clear-water epeiric or shelf seas adjacent to low lands with mild climates.

White chalk is a very fine granular limestone, composed in the main of entire or broken calcareous tests of floating or bottom-living Foraminifera (Fig. 485) and of parts of exceedingly small floating calcareous algæ (Rhabdospheres and Coccospheres, described later). With them are often associated many kinds of shallow-water, thick-shelled, bottom-living invertebrates, such as sea-urchins, bryozoans, brachiopods, and molluscs. In Europe the chalks frequently abound also in flints of different shapes and sizes, but in America these secondary alterations are rarely met with. They probably were formed after the chalks had been raised above sea-level, when the atmospheric waters circulating through the porous chalks dissolved the colloidal silica of the sponge spicules

and deposited them as the flints, just as the cherts of limestones are made during the weathering process (see pp. 274 and 437). The flints occur most often along the bedding planes, but are also frequently seen in more or less vertical lines and along the joint planes.

Rhabdospheres and Coccospheres. — The Cretaceous chalk of Europe abounds in the broken parts of microscopic lime-secreting plants, or algæ, known as Coccospheres and Rhabdospheres (Fig. 332). In the present oceans such organisms are characteristic of tropical and subtropical regions, but in the Globigerina oozes their remains are always overshadowed by the greater abundance and larger size of the pelagic foraminifers. Murray states that these pelagic calcareous algæ are so fragile in texture that it is principally their broken-down parts that occur in the oozes, though in places entire specimens of the smallest-sized Coccospheres abound. It is the tiny parts of these calcareous algæ, however, that make up a large portion of the finest materials of the chalks.

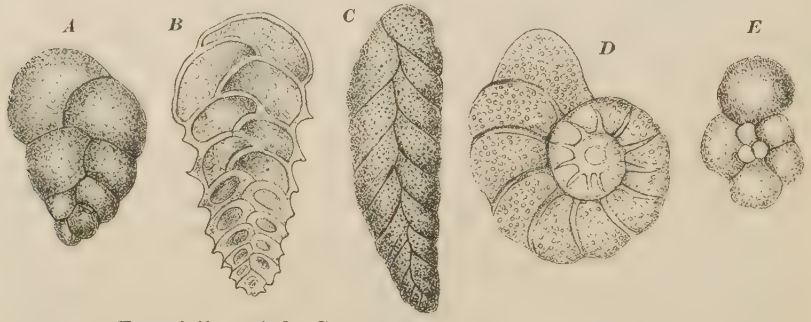


Fig. 485. — Foraminifera of the Cretaceous, greatly enlarged. From Geol. Surv. of Minnesota. *A*, *B*, Two species of *Textularia*. *C*, *Bolivina*. *D*, *Anomalina*. *E*, *Globigerina*.

Foraminifera. — As the chalk deposits are composed in the main of the remains of Foraminifera, it is now necessary to describe these (see Fig. 328, Pl. 20, Figs. 1, 2, Pl. 23, Figs. 1, 2). The name Foraminifera means *having foramina* or holes in the shell, this being the characteristic feature of many of these tiny marine animals, more than two thousand kinds of which are known (Fig. 485). In size the average specimen is smaller than a pin-head, and each individual consists of a single cell of protoplasm, in which all of the functions of life dwell. They constitute one of the divisions in the most primitive stock of animals known as the Protozoa (see pages 415 and 479). The simplest forms (*Amœba*, Fig. 312) are devoid of a shell and the shape of the animal is constantly changing, in that blunt processes are protruded in the direction of movement,

and as they crawl, these pseudopodia, or false feet, as they are called, engulf other organisms on which the Protozoans feed. There is therefore no mouth or stomach, and digestion takes places anywhere within the protoplasm. In the Foraminifera the pseudopodia are more thread-like and issue through the foramina of the shell, or, where these are absent, through a single orifice.

In the protoplasm also lie one or more large, rounded, variable cavities, the *contracting vacuoles* (Fig. 312 *D*, *V*), pulsating organs that have an excretory function and serve to get rid of the finer waste products. Near the center of the cell lies the very important and very complex structure known as the *nucleus* (Fig. 312 *D*, *N*), and here it is that the main vital energy and reproductive processes lie. As a rule, increase in individuals takes place by simple division, beginning first in the nucleus and then going on throughout the cell substance, or the individuals may encyst and develop into many spores, each one of which, when liberated, grows into another individual. In many cases, however, simple division does not continue until complete separation into two individuals takes place (as in Fig. 312 *C*), but the new cells remain united to one another in a definite pattern (as in Fig. 328 *B*, *C*), forming more or less ornate and small or large colonies. In this way thousands upon thousands of individuals may live in a colony, making calcareous structures sometimes as large as 3 inches across.

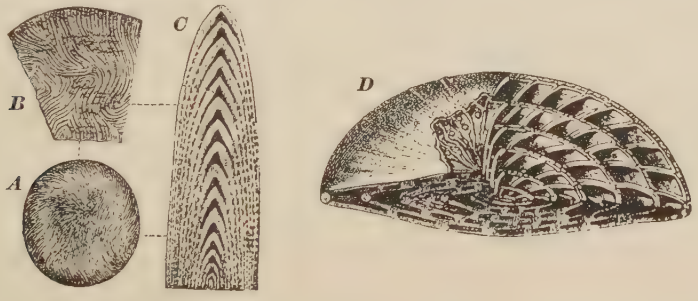


Fig. 486. — Foraminifera (*Nummulina*) in large colonies, from the Eocene of Egypt. From Steinmann's *Einfiihrung in die Paläontologie*. *A*, colony, nat. size. *B*, surface enlarged to show canals. *C* and *D*, portions enlarged to show individual cells or chambers.

Foraminifera are known as fossils since the Cambrian, but did not become geologic factors as makers of limestone until Mississippian time (Pl. 20). In the Pennsylvanian rocks the fusulinid colonies often look like grains of wheat (Pl. 23) and in the early Permian they attained to lengths of an inch. These forms often made limestones and are widely known throughout the northern hemisphere. Throughout the Mesozoic strata, foraminifers are usually present, though commonly in colonial forms of small size, but they are especially abundant after the Middle Jurassic (Fig. 485). The time of dominancy of large colonial forms, however, was during the Eocene in the Tethyian waters. These forms were

the nummulinids (from the Latin *nummus*, a coin), which make coin-shaped colonies usually about three fourths of an inch across, though in cases reaching nearly 8 inches (Fig. 486). They have made a wonderful amount of limestone, especially in the seas now occupied by the Sahara Desert, where the Great Pyramid is built of such stone. After Eocene time, the large colonial forms were no longer abundant and with the warm seas of Oligocene times the modern floating or pelagic kinds took their rise.

Radiolaria. — Another stock of Protozoa related to the Foraminifera are the Radiolaria, so named because of their radiate structure. Their shells are very ornate (see Fig. 330). They are, however, much smaller animals than the foraminifers. Most of them are pelagic in habit, that is, they float in the water of the oceans. Haeckel has published a large volume on the living species gathered by the Challenger Expedition, and in this work he describes 4318 species in 739 genera.

The shells of radiolarians are siliceous and much perforated, and because of their indestructibility the animals are important as rock makers, as is seen from the radiolarian abyssal oozes of the present oceans (see page 480). In the past they have built many fine-grained, siliceous, often red, jasper-like rocks (radiolarites) such as those in the city of San Francisco, California, which are of Miocene age. The oldest Radiolaria occur in the Proterozoic. It should be added here that radiolarian limestones may also be formed in shallow seas, as shown in the Carboniferous of England.

CHAPTER LI

THE CRETACEOUS PERIOD AND THE LARAMIDE REVOLUTION

The Cretaceous system of rocks was the last one formed in the Mesozoic era. The way in which the system received its name from the chalk has been dealt with in the last chapter, and it only remains to be said here that as the lithologic term has been so long in use and is so widely known, the best policy seems to be to continue it.

Extensive Cretaceous Submergences. — The Cretaceous was the time when the oceans spread over the peneplained lands apparently more widely than at any other known geologic period. Suess first pointed out this great marine spreading, and it is illustrated in Fig. 488.

The Cretaceous is now divided as follows:

Fig. 487. — Eduard Suess (1831–1914), author of *Das Antlitz der Erde.*

Europe	Great Plains	Texas	Gulf States	Atlantic Coast
Break	Denver, Arapahoe (Shoshone and Lance)		Break	Break Manasquan
Danian	Laramie	Break		
Sênonian	Pierre-Fox Hills: Bearpaw, Judith River, Claggett, Eagle (Montana series)	Navarro (Gulf series)	Ripley	Rancocas Monmouth
		Taylor (Gulf series)	Selma	Matawan
Turonian	Niobrara, Benton (Colorado series)	Austin, Eagle Ford (Gulf series)	Eutaw	Magothy
Cênomanian	(Bear River)		Tuscaloosa	Break Raritan
	Dakota Break	Woodbine Break (Gulf series)	Break	Break

Pacific Overlaps on America

Overlying the Comanchian or Shastan strata disconformably, but usually unconformably, is the Chico series of sandstones and shales, with local conglomerates and coal beds. These coarse deposits and thick formations are found all the way from the Lower Yukon, the Alaskan peninsula (1000 feet), Queen Charlotte (11,000 feet) and Vancouver islands (5000 feet), middle and southern Oregon (4000 feet), the Sacramento valley (9500 feet), and the Coast Range of California, to San Diego and the peninsula of Lower California, as far south as 31° 30′. In California there were two periods of volcanic activity and in the Queen Charlotte Islands one of long endurance (see Pl. 36).

These beds begin somewhat earlier in time and continue longer than those of the Colorado series of the great Interior or Coloradoan sea, but do not embrace, according to Stanton, the youngest Cretaceous time.

The Chico faunas were essentially molluscan, and, like those of the earlier Shastan (Horsetown), were of the Indo-Pacific province, and were markedly different from those of the Coloradoan and Mexican seas. A few species of bivalves were common to the two areas mentioned, but these forms were world wide in their distribution. The evidence, then, is decidedly in favor of the view that the Pacific overlap was barred by a land barrier, the rising Rocky Mountains, from entering the Coloradoan epeiric sea.

Great Inland or Epeiric Sea

Coloradoan Sea. — The previous Comanchian submergence finally vanished from all or at least the greater part of the North American continent. After an interval of unknown duration the Gulf of Mexico again began to invade the continent, and more extensively than ever before during the Mesozoic. This was the Cretaceous overlap of vast extent all along the region east of the rising Rocky Mountains from central Mexico into the Arctic Ocean. The invasion began earliest in the Gulf border area, spreading sandstones as a rule in the United States and Canada (Dakota formation) and then muds (Benton) when the sea attained its greatest proportions. In many places, however, the sediments did not begin with sands but with muds. Further, it is probable that the invasion began about the same time in the Arctic region, spreading southward and uniting with the waters of the Gulf of Mexico. This, then, was the great inland Coloradoan sea, and its deposits rest unconformably upon the earlier formations. It takes its name from the older Cretaceous formations, the *Colorado series*, so well developed in the state of that name. This series then continues

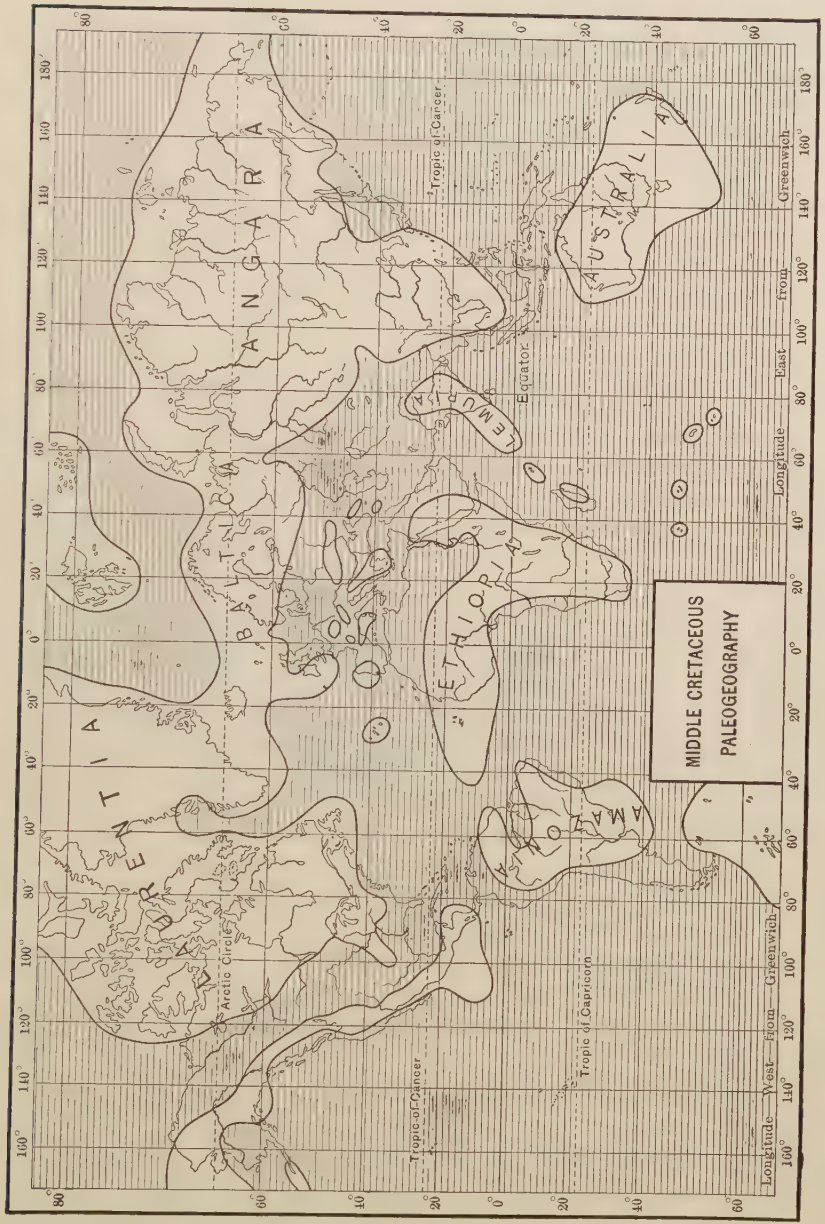


Fig. 488. — The great Middle Cretaceous transgression of the oceans over the lands. In the main after De Lapparent.

unbroken into the upper one, the *Montana series*, of somewhat smaller sea extension (see Pl. 36).

The deposits of the Coloradoan sea are very variable from place to place, and while in the main made up of muds and sands, there are areas of chalk and limestone deposits (Niobrara formation, 200 to 1500 feet thick) in Texas and extending from Kansas and Colorado north into Canada. In general, the formations are thickest in the west, where the materials came from the periodically rising Rocky Mountains, so that brackish and even fresh-water deposits are more frequent here than in the eastern part of the Coloradoan sea. For this reason the greater amount of coal (bituminous and lignite) occurs in the western areas of this seaway. While the coal marshes

Fig 489. — Conformable contact of Cretaceous shales on Devonian limestones (at dotted line near water), 4 miles below Fort McMurray, Athabasca River, Alberta, Canada. Photograph by F. J. Alcock, Geol. Surv. Canada.

were of greatest extent toward the close of the Cretaceous, some coal was laid down in various places throughout this period, evidence which indicates that the sea was shallow, with many deltas in the western area, along with bars and marshy islands, ever changing from place to place, due to the shifting sea currents, the unloading rivers, and the crustal warpings. Finally, the entire Coloradoan basin was silted full, and with the final decided elevation of the Rocky Mountains, this epeiric sea vanished.

In Iowa and Minnesota the Cretaceous deposits are thin, ranging from less than 100 feet to 500 feet, though embracing only the older half of the deposits (Dakota formation and Colorado series). West-

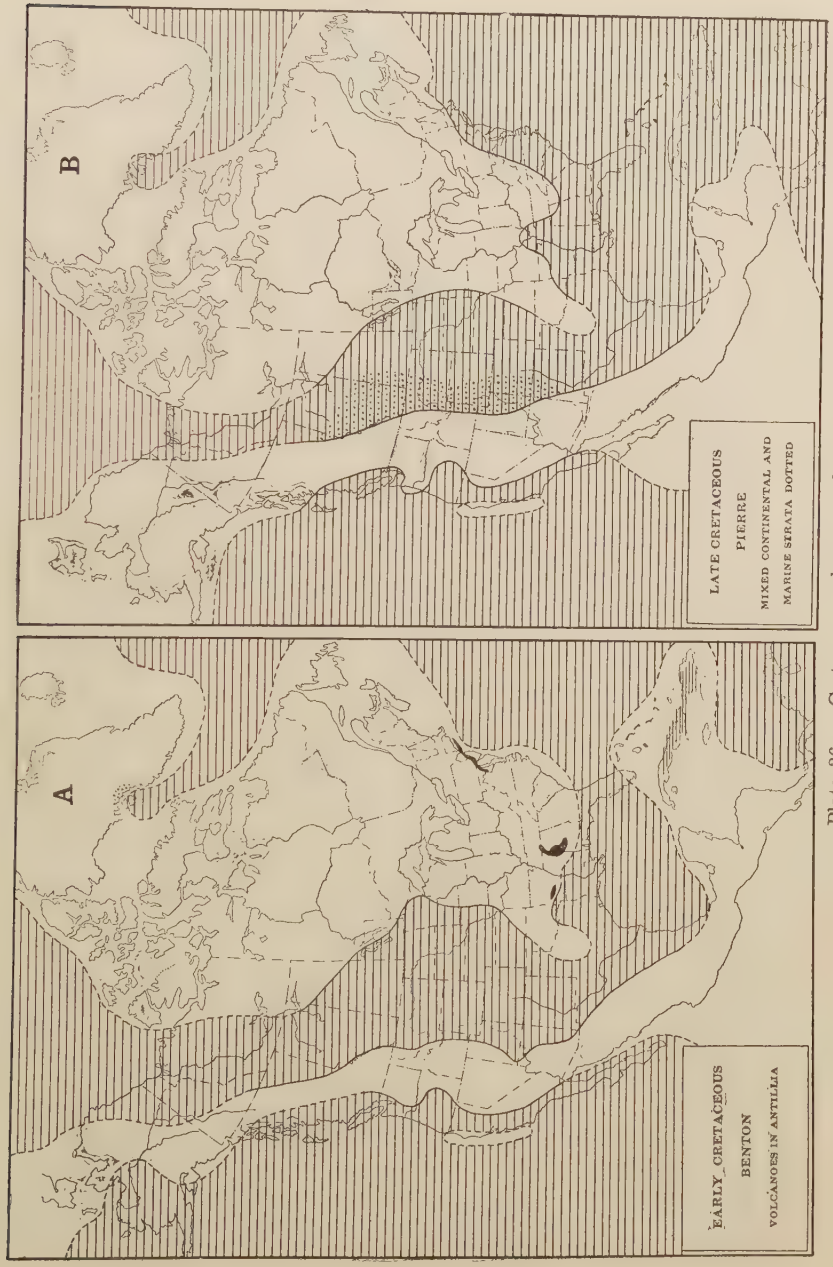


Plate 36. — Cretaceous paleogeography.

ward the formations thicken rapidly, and the rate of deposition increases with time, so that in South Dakota and northwestern Nebraska the depth of the strata is about 4000 feet. In northern central Wyoming and the Great Plains in general, the thickness is about 10,000 feet, and finally in southwestern Wyoming the sections range from 13,000 to over 20,000 feet. These great thicknesses lie in the deepest western part of the basin, and in a general way it can be said that the deposits thin out irregularly both to the north and to the south, though there are notable exceptions to this, as in southwestern Colorado, where the maximum depth is given as less than 7000 feet. In the Big Horn coal basin of Alberta, the thicknesses are also considerable, being about 6200 feet, and this depth is maintained northward into the Saskatchewan country. Still farther north the depths are greatly reduced.

Toward the close of the Cretaceous (Laramie) nearly all of the sea-ways changed from marine to fresh-water conditions, and the sediments were coarse materials (sandstones), often derived from lavas (largely andesites), and ranging in thickness up to 6500 feet. However, at intervals the sea reappeared for a short time throughout the area of the Great Plains, depositing beds a few feet in thickness made up almost entirely of oyster shells. These oscillations of the sea and the general vanishing of the marine waters are prophetic of the coming Laramide Revolution.

Marine Faunas. — The faunas of the Coloradoan sea were made up almost entirely of molluscs, of which the bivalves (*Inoceramus*, with a length of 3.5 feet) and gastropods had the greatest specific development, while the ammonids, now greatly reduced in numbers, are still most significant in determining the geologic age of the strata (see Pl. 37). Corals, sea-urchins and brachiopods, so common in Europe, are almost unknown in deposits of this sea north of Texas. The Coloradoan faunas have their own aspect, with the greatest number of species in common with the Mexican sea and the least with the Atlantic overlap.

Vanishing of the Inland Sea

Final Continental Deposits. — We have seen that the marine Cretaceous of the Rocky Mountains region also has a considerable amount of fresh-water formations, and that the latter tend to recur oftener toward the close of the period. Over them often lie other fresh-water deposits of admitted Tertiary age, and while in places geologists are agreed as to the line of separation between the Cretaceous and Eocene, from the time work was begun in this region of the Great Plains, investigators have often been in doubt as to the division line. In the last ten years this question of classification has become acute, and though many of the best geologists and

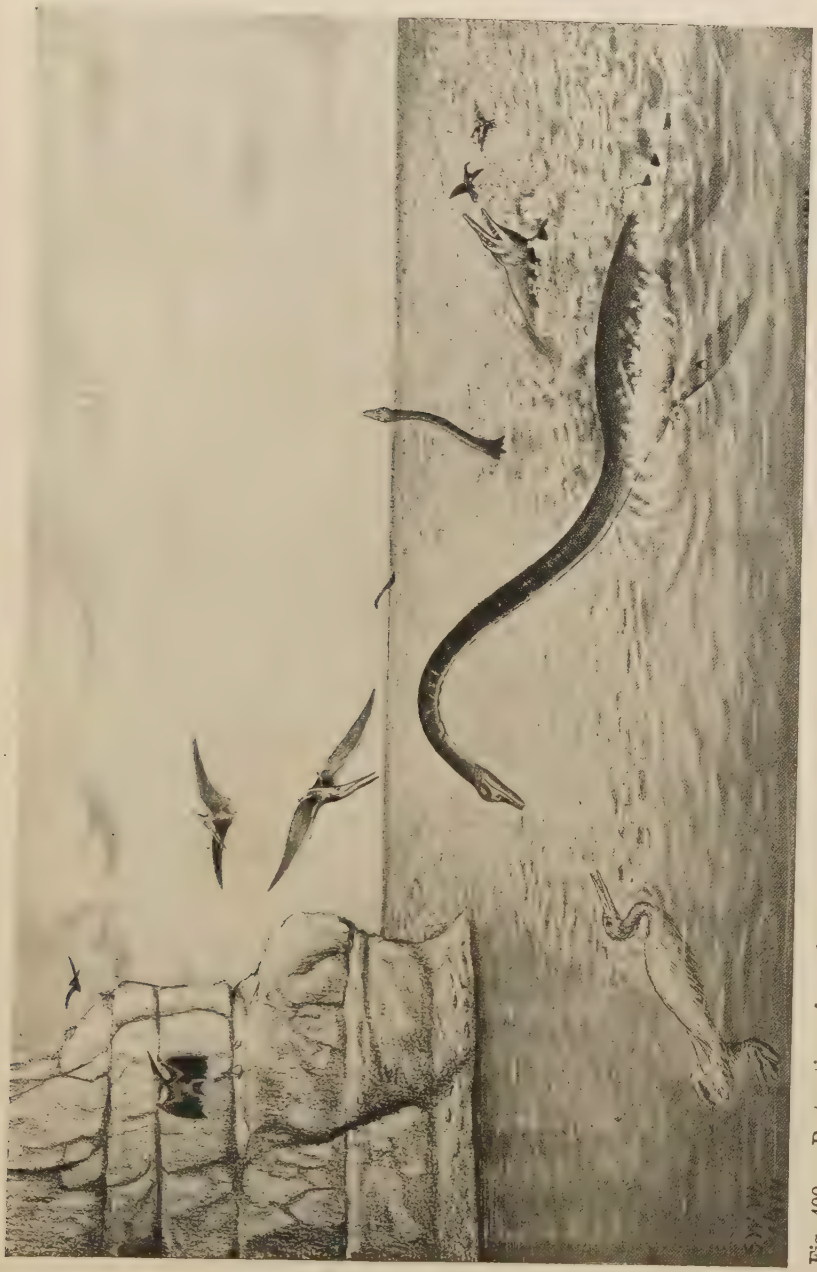


Fig. 490. — Restorations of vertebrates of the Cretaceous seas of Kansas. The long-necked reptile attacking the wingless reptilian bird (*Hesperornis*) is a plesiosaur (*Elasmosaurus*); the flying reptiles on the left are dragons or pterosaurs (*Pteranodon*); on the right is a fish-lizard (*Ichthyosaurus*), attacking winged reptilian birds (*Ichthyornis*). After Williston. From University of Chicago Press.

paleontologists have labored toward its solution, the problem is not yet adjusted. The field relations of the formations are fairly well known, but how much value shall be ascribed to the unconformable and disconformable contacts between the series of strata is still an unsettled question. As the sediments come from the same western source as those of the previous formations, they are consequently very much like the older ones. Again, the fossils are not markedly different in their evolutionary change because there is no great lapse of time between the accepted and the debatable Cretaceous formations. There is no lack of fossils in these beds and the difference of opinion among the stratigraphers lies in the fact that the students of invertebrate and vertebrate life find the Cretaceous faunas continued into beds which the paleobotanists hold have floras that are clearly like those of Tertiary time (Fort Union). Or, briefly put, in the same strata the animals appear to be of Cretaceous time while the plants seem to be of the early Tertiary.

The great changes in the animal assemblages of the higher or Tertiary era seen in the rapid vanishing of the old forms and the arrival of unheralded migrants from unknown regions, along with a notable alteration of the climate to somewhat cooler conditions, come later. The age of these younger fossils is not questioned, since they are admitted by all to be of earliest Tertiary time (Fort Union, Puerco, Torrejon formations). In other words, the latest Cretaceous faunas are not transitional in character, while the dinosaurs (of the Lance) continued to live on for a time longer because there was as yet no marked change in their environment. What we have here is a partial record of the interval between the Mesozoic and Tertiary eras, a record that is usually absent at these " critical times." The majority of paleontologists, therefore, prefer to believe that the time is still Cretaceous, though it may later be deemed advisable to say that these persistent faunas continued into earliest Tertiary time. Usually our classifications recognize the beginning of a new history or period by the arrival of strangers, forms prophetic of coming dynasties, and this is what the plants show, but the animals of the lands unfortunately negate this evidence.

Floras of the Final Cretaceous. — As the line of separation between the Mesozoic and Tertiary in the Rocky Mountains is dependent upon the fossil evidence of the strata we must digress a little and present the latter in this place. The latest Cretaceous continental formations (Lance, Denver, Arapahoe) have yielded a flora of 193 species, and of these 84 are specifically identified. It was almost wholly an angiosperm forest flora, of which at least 3 species are still living, a condition unknown in floras of earlier times. Further, it abounded in

poplars (13 species) and planes (8), and of the significantly warm climate trees it had figs (3), magnolias (1), and palms (4). Of this flora about 13 per cent was derived from the Cretaceous, while 81 per cent was Tertiary in character and continued into later times.

Animals of the Final Cretaceous. — Of the described fresh-water shells there are about 39 forms, and of these the unionids were the most prolific (25 species). As these shells were more like those of the earlier Cretaceous, they have little significance as time markers. The rest of the animals, however, were all of Mesozoic types. The mammals were still archaic, and the dinosaurs, of which there is a wonderful record, were absolutely Cretaceous in character, and the last of their race (see Pl. 33). In their evolution they contrast so decidedly with the changing flora that we are compelled to say that the late Cretaceous reptiles were living in a forest of Tertiary aspect. The death knell of the dinosaurs came with the complete vanishing of the Cretaceous epeiric seas and swamps, for none of them are known in accepted earliest Tertiary strata (Fort Union). It may be that their going was further brought about by a somewhat cooled climate, as is seemingly indicated by the Eocene (early Tertiary) glacial deposits or tillites of southwestern Colorado.

Seas of the Final Cretaceous. — In various states of the Great Plains, evidences of late Cretaceous seas are found, the most interesting of which is that of the Cannonball member of the Lance formation of North Dakota, with a known extent of 130 miles. Lloyd divides the Lance into a lower member of continental deposits (400 feet), with dinosaurs, and a flora that Knowlton says is indistinguishable from the plants of the Fort Union (Eocene); and an overlying marine Cannonball member (300 feet), with an invertebrate and vertebrate fauna of over forty species that are very closely related to those of the earlier marine Cretaceous (Fox Hills).

Gulf of Mexico Shelf Seas

Mexican Overlap. — The great inland sea described in the previous pages opened out into the Gulf of Mexico across Texas, where the waters lay upon the margin of the continent and are therefore better referred to as shelf seas. These marginal overlaps came from the Gulf of Mexico and extended all the way from central Mexico across the Gulf States to unite finally with the shelf seas of the Atlantic Ocean.

In southern Texas on the border line of Mexico (Eagle Pass), Cretaceous time is fully represented and there are here about 6550 feet of strata that in the lower portion are made up of clays, marls, chalk and chalky limestones (the Austin chalks and limestones are 1500 feet thick), while the upper 4000 feet consist largely of sandstones and clays, with valuable coal beds, which recur in the state of Coahuila (see Cretaceous-Eocene contact, Fig. 491). The Cretaceous is also well developed throughout northeastern Mexico and as far south as San Luis Potosi in central Mexico, where the Cardenas limestones have an estimated thickness of 1800 feet. South of this

region the formations gradually vanish, and none are known in southern Mexico and the greater part of Central America.

Antillia. — Cretaceous deposits are known in many parts of Cuba, consisting here of magnesian marls and glauconitic limestones. They occur also in San Domingo and Jamaica, where the Blue

Fig. 491. — Projecting ledges of Eocene (Midway) limestone of the Tertiary resting on Cretaceous shale (Escondido) at White Bluff, Rio Grande, Texas. Note the conformable contact. Photograph by L. W. Stephenson, U. S. Geol. Surv.

Mountain series, 5000 feet thick, begins with tuffs and lavas, passing into dark colored shales, marls and limestones, all resting unconformably upon metamorphosed and igneous formations of older age. These deposits were greatly deformed and injected by igneous material before the opening of Tertiary time, according to Hill.

Life of the Antillian Seas. — The fauna of the Mexican and Antillian seas was of the normal marine type, and of warmer waters. While the molluscs abounded here, the foraminifers, corals, and especially the cemented bivalves (rudistids, Fig. 494) flourished.

Western Gulf Border. — The Gulf of Mexico in Cretaceous times also spread widely over the Gulf States from Texas to Georgia (see Pl. 36). The overlap appeared earliest in Texas in harmony with the early origin of the Coloradoan sea, and did not begin to spread actual marine deposits east of the Mississippi River until the second half of Cretaceous time (Montana). We have seen that

the Cretaceous in southern Texas (Eagle Pass) has a thickness of about 6550 feet, thinning to about 4000 feet in the northeastern part of the state, where the whole of this period is represented by marine beds. Farther east in Arkansas the shore phase of the system is thin, and only the Upper Cretaceous is present, but in Louisiana beneath the Tertiary overlap probably all of the strata are present.

Eastern Gulf Border. — The trough of the Mississippi River is occupied by rocks younger than the Mesozoic, and therefore nothing of these strata is seen except in extreme western Tennessee and southern Illinois. Here on the higher eastern land of the trough,

Fig. 492. — Uneven (erosional) contact of Tertiary marine sands (Midway), with calcareous concretions, on Cretaceous chalk (Selma), at Old Canton Landing, Alabama River, Alabama. Photograph by L. W. Stephenson, U. S. Geol. Surv.

Cretaceous formations that are practically unconsolidated are met with from Tennessee through eastern Mississippi into Alabama and Georgia (see Cretaceous-Eocene contact, Fig. 492). Nearly everywhere they overlap Paleozoic strata, and in Georgia they rest on the more ancient crystallines (Pl. 36). The invasion is variable in time and character of deposits from place to place, beginning as a rule with fresh- to brackish-water sandstones that pass into clays and marls and locally into a thick deposit of impure chalks. The "rotten limestone" or Selma chalk formation of Upper Cretaceous age in western Alabama and eastern Mississippi is 1000 feet thick, but east and west of this area the calcareous deposits are replaced by

marls, clays, and finally sandstones. The thickness of these eastern Cretaceous deposits does not exceed 1300 feet, and usually ranges nearer 500 feet.

Life of the Gulf Seas. — The younger Cretaceous faunas (Montana) of Texas are more harmonious with those of Mexico than with similar horizons of the Coloradoan sea, being probably of waters with a higher temperature. Those of the eastern Gulf border take on more and more of the Atlantic border elements. Almost none of the warmer water rudistids and corals appear east of the Mississippi trough, though foraminifers, sea-urchins, and brachiopods occur here and northeastward, indicating the marine purity of the waters.

Atlantic Shelf Sea

Atlantic Coast. — Upper Cretaceous formations are known all along the Atlantic border, either beneath or inland of the Tertiary marine strata from South Carolina to the south coast of Massachusetts (see Pl. 36). They all dip seaward, though their original position is now warped due to elevating in the west. East of New Jersey the outcrops are scattering and mainly of brackish-water origin, while south of Maryland these deposits are only seen in the river valleys beneath the Tertiary. Therefore the area yielding most information is in New Jersey and Maryland. Here the deposits average between 1000 and 1325 feet, of which the lower 400 to 600 feet are either of fresh-water or brackish-water origin. Here, too, the materials are unconsolidated, and consist in the lower half of gravels, sands, and clays with lignite, while the upper portion is made up of clays and sands becoming more and more glauconitic and finally going over mainly into greensands. Glauconite is characteristic of the Atlantic overlap and at times is also found in considerable quantity in the eastern Gulf border.

Life of the Atlantic Cretaceous. — The marine invertebrate faunas are large, consisting of about 600 forms, in the main Mollusca (Pl. 37). Weller says that many of these have a wide distribution, as many of the New Jersey species also occur in the Gulf border area and mainly east of the Mississippi River. Further, the faunas indicate late Cretaceous time (Montana), and while definite but broad correlations can be made with the formations of the Coloradoan sea, there are not many species in common between the two widely separated areas with which this can be done. The floras occur mainly in the basal formations, where 150 forms have been discovered, and according to Berry their characters indicate a mild climate without marked seasonal changes.

Laramide Revolution

Laramide Volcanoes. — In describing the Cretaceous formations of the Rocky Mountains it was said that more or less of elevation was going on throughout this period, and that toward the close

much lava was ejected and eroded into the andesitic débris seen in the latest marine formations and the subsequent continental deposits. These eruptions continued with unabated vigor into Eocene time, and the volcanoes extended from Mexico City and Arizona north into Canada (see Pl. 36). Volcanoes were also active at this time in Chili, and in peninsular India occurred the *Deccan lava flows* through fissures, the most stupendous eruptions known to geologists, covering an area of 200,000 square miles and ranging in thickness up to a mile or more.

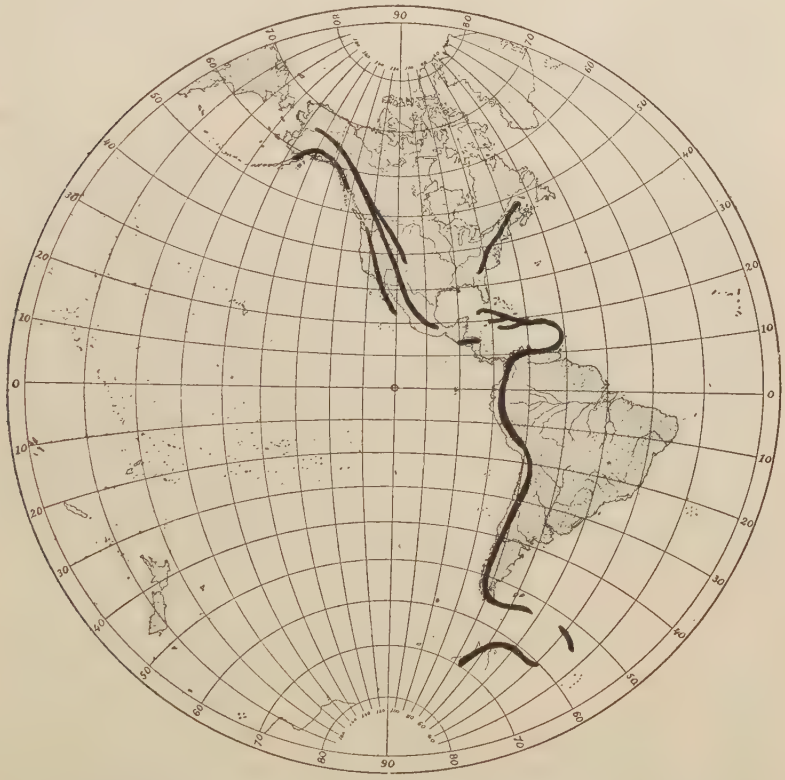


Fig. 493. — Stereographic map of the western hemisphere, after Penfield, showing the Laramide, Antillian, and Andean regions of folded mountains of Cretaceous origin. The Appalachian area was also elevated.

Laramide Mountains. — These volcanic eruptions were but symptoms of crustal movements, for mountain making of a folding nature and due to lateral thrusting toward the east (see page 345) on a vast scale was going on during late Cretaceous time. These movements, though of less intensity, were repeated in the early

Tertiary, and, while the Laramide orogeny was equalled only by that of the closing period of the Paleozoic, it was exceeded by the deformation of late Tertiary time. These movements constitute the Laramide Revolution of Dana. The area affected embraced the mountains of western North America and the Andes of South America as well — two grand mountain chains that extended from Cape Horn to Panama, and from southern Mexico to Alaska — and during the revolution some of the ranges in North America are thought to have had an altitude of 20,000 feet. At the same time the Appalachians were reëlevated, not due to horizontal thrusting but to geanticlinal areal uplift (see page 370), about 2000 feet, and the Antillian mountains were also thrown up higher (see Fig. 493).

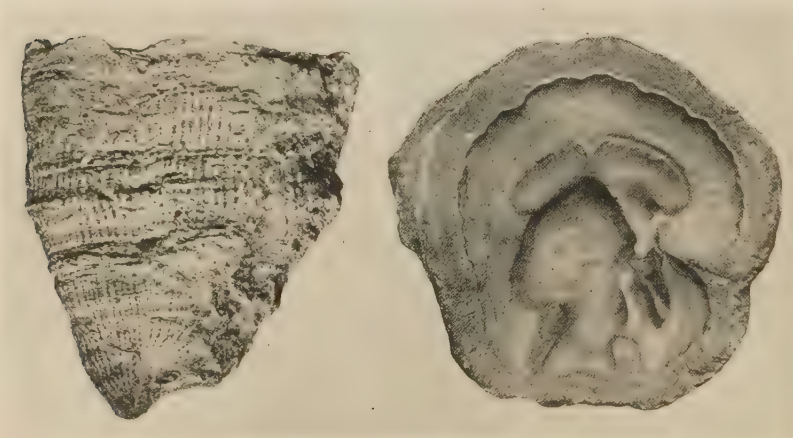


Fig. 494. — Reef-making, coral-like, rudistid bivalves (*Hippurites radiosus*), from the Cretaceous of France. About half nat. size.

Climate of the Cretaceous

The wide distribution of very similar Cretaceous floras, including palms and some fig trees, from Argentina to Greenland and Alaska, indicates, according to Knowlton, a somewhat warmer climate than at present, and one of a moist mild nature in the Rocky Mountains area during the time of the Coloradoan sea.

It is very probable that climatic zones also existed then, though not in so marked a degree as now. This is best seen in the distribution of the marine faunas, for in the Cretaceous formations of Tethys, Antillia, Mexico, and Texas, reef-building corals and bivalves (rudistids, Fig. 494) are conspicuous, while in the deposits

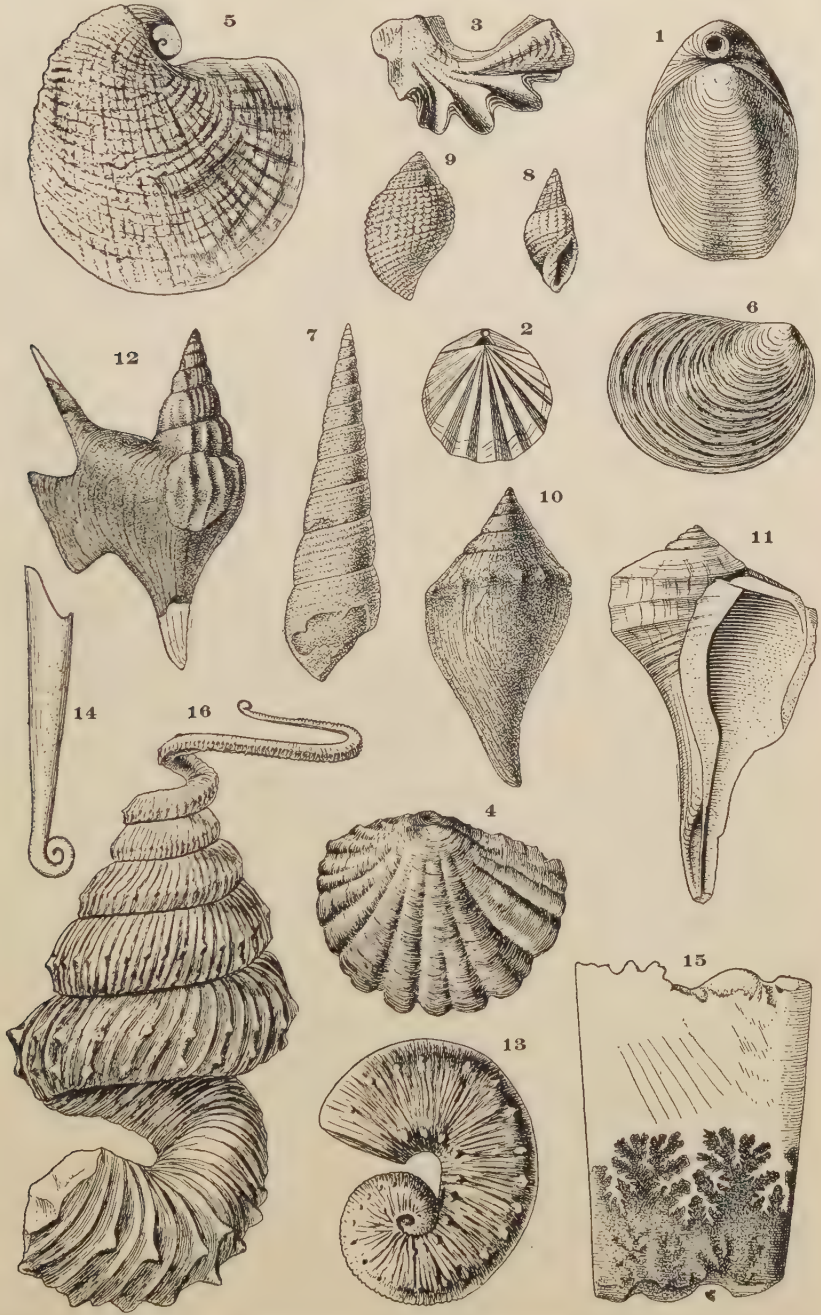


Plate 37. — Cretaceous brachiopods (1, 2) and molluscs (3–16, 3–6 bivalves, 3, 4 oysters, 7–12 gastropods, 13–16 cephalopods or ammonids). See Appendix B.

of North Europe and the American Atlantic border these animals are absent.

We have seen that the Cretaceous closed with the Laramide Revolution, and in harmony with the earlier and later diastrophic movements of similar import, one expects to find here a cold, or at the least a considerably cooled climate the world over, and especially in polar lands. However, no one has yet discovered tillites that were formed during the latest Cretaceous, and even though marked changes took place in the animal world during the Epi-Mesozoic interval and earliest Eocene time, the floras indicate plainly that there was no cold climate accompanying the Laramide Revolution. In the Eocene of Colorado there are local tillites, but these apparently indicate restricted Alpine glaciers and not a world-wide glacial climate.

Two beds of till, presumably from Alpine glaciers, were discovered by Atwood in 1913 in southwestern Colorado, and while their age is not yet determined in detail, Cross holds that they are of early Eocene time. (See page 913.)

Life of the Cretaceous

The life of the Cretaceous was the culmination of the dinosaurs, pterosaurs, and reptilian mammals that began in the Triassic, the toothed birds of Jurassic origin, and the marine faunas of Jurassic time. It was the final expression in the evolution of the medieval life, and out of it arose the modern world of organisms.

Marine Invertebrates. — The invertebrate animals of the Cretaceous seas were much like those of the Comanchian (see Pl. 37), with the marked difference that the ammonids were making their last but ineffectual stand. Old age was upon them and their doom was foreshadowed in the uncoiling, the unnatural twisting of the shells (Pl. 37, Fig. 13), and the straight baculites (Fig. 495, and Pl. 37, Figs. 14, 15). The genus *Heteroceras* displays the extreme of irregular growth (Pl. 37, Fig. 16). The belemnids were still present in force, though by no means so abundant as in the Jurassic, and they were evolving toward the squids in the loss of their internal vestigial structures.

Land and Fresh-water Shells. — The unionids or pearl shells were common, and very much like those now living in the western streams of the United States. Fresh-water snails and land snails (*Helix*, Fig. 376 *C*) are also found, though less commonly.

Floras. — There was nothing medieval in the character of the Cretaceous flora, for more than 90 per cent of the plants were of

the kinds known to-day. The magnolia, fig, and sassafras trees, of Comanchian origin, were in their best development in the Cretaceous. Other modern trees that appeared in this period were the birch, beech, maple, oak, walnut, hazelnut, plane, tulip, laurel, holly, ivy, sweet gum, and bread-fruit. The giant trees of California, the sequoias, of early Mesozoic origin, were also in their

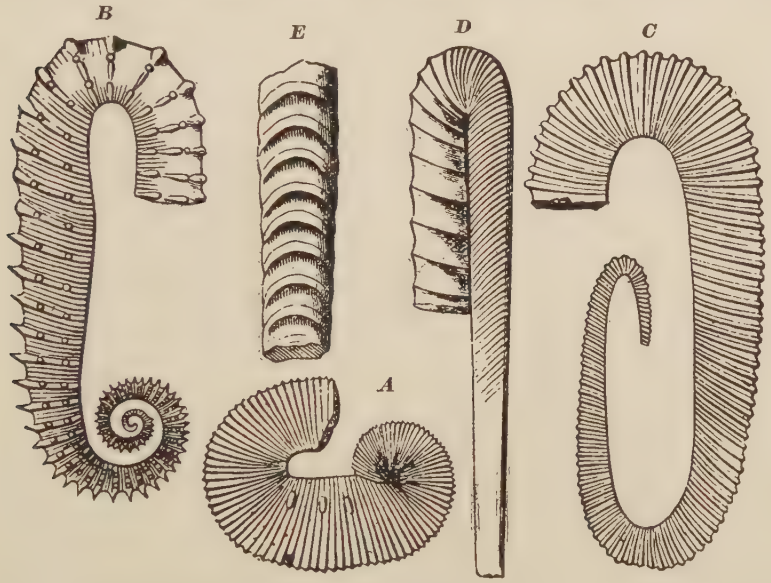


Fig. 495. — Old-age ammonids of the Comanchian and Cretaceous of Europe. From Heer's *Primeval World*. See Appendix B.

ascendancy. The sedges and grasses appeared in Cretaceous time, but it was not until late in the Eocene that the latter and the cereals became abundant, and thus made possible the rise of the higher or placental mammals.

Dinosaurs. — The ponderous, quadrupedal, sauropod dinosaurs of the Comanchian failed to continue their existence into the Cretaceous of North America. With respect to other types of dinosaurs we may say that those of the Cretaceous were more varied and are better known than those of earlier times. The duck-billed, bipedal, plant-feeding dinosaurs were well represented by distinctively American types in New Jersey and especially in the Rocky Mountains (*Trachodon, Claosaurus,* Pl. 33, Fig. 6). On the other hand, the armored dinosaurs that appeared in the Comanchian (*Stegosaurus,* Pl. 32, Fig. 5) are represented in the Cretaceous rocks by different types.

The most common and characteristic of the herbivorous dinosaurs of this time, however, were the Ceratopsia, horned animals, sometimes twice as heavy as and larger than elephants. They are called Ceratopsia (Greek *keras*, a horn) because they have on their heads two or three large horns (Pl. 33, Figs. 1–5). In some ways these animals looked like huge rhinos, but this is merely an external resemblance, for the latter are mammals. However, the Ceratopsia were great fighters among themselves, and against the flesh-feeding dinosaurs their sharp horns must have been formidable weapons. They appear suddenly in the Upper Cretaceous of America, having migrated there from some unknown region.

All of the kinds of dinosaurs mentioned were plant-feeders, and as is the law in nature, they had their carnivorous enemies, the large theropod dinosaurs. Of these there were several kinds, but the most terrible of all in size, weight, and ferocity was the form called by Osborn the King Tyrant Saurian (*Tyrannosaurus rex*), probably the mightiest flesh-feeder of all time, carrying his head 16 feet above the ground and measuring 40 feet along the vertebral column (see Pl. 33, Fig. 7).

At the very close of the Cretaceous, the life of the land was still dominated by the dinosaurs, and nearly all were large compared with the average size of the stocks from which they were derived. Even though the great inland sea along whose shores they lived was vanishing, and the Rocky Mountains were rising, they still lived on without apparent check. It seems probable that some even lived over into Tertiary times, but apparently not long, for the dawn of the Recent was upon them, and the changed environment with its modernizing flora was bringing in a migrant horde of more intelligent and active competitors in the placental mammals. These fundamental changes, accentuated by a cooler climate, brought about their extinction.

Pterosaurs. — Flying reptiles or pterosaurs of early Cretaceous time are known in gigantic species that sailed in swarms over the Kansas seas, their skeletons being common in the deposits of that state (see Fig. 490). They were without teeth and tail, the head was more than 3 feet long, and narrow, while some forms had a long, rudder-like crest extending backward from it 2 feet. They soared over the sea and, diving, like ospreys, picked out of it the fishes on which they fed. Their bones were light and hollow, and their bodies comparatively small when compared with the wing expanse, which in the largest known individual was 25 feet across. These pterosaurs were the organic aëroplanes of Cretaceous time, and

from a study of them Langley obtained hints for his invention of the first flying, or rather soaring, machine of to-day.

Reptiles of the Sea. — The seas of Cretaceous time continued to be dominated by reptiles. The ichthyosaurs were vanishing, but the plesiosaurs attained their culmination, for a form has been found in Kansas which attained a length of 40 to 50 feet, of which 22 feet was neck (*Elasmosaurus*, Fig. 490). The crocodiles were represented by the ancient broad-nosed, long-headed type (*Teleosaurus*), and by the first of the slender-nosed kinds, such as the gavials living to-day in the rivers of India and Borneo. Of marine turtles, at least one kind was present; the largest specimen known was nearly 11 feet long, with a breadth across the front flippers of 12 feet (*Archelon*). But the most interesting of the newly appearing animals were the scaled reptiles known as mosasaurs, which were confined to the Cretaceous. They swarmed in the shallow seas along the Atlantic border and the Gulf of Mexico, and especially in the seas of Kansas. The mosasaurs were gigantic, carnivorous, marine lizards, ranging in length up to 23 feet, with the limbs modified into swimming paddles (see Fig. 496).

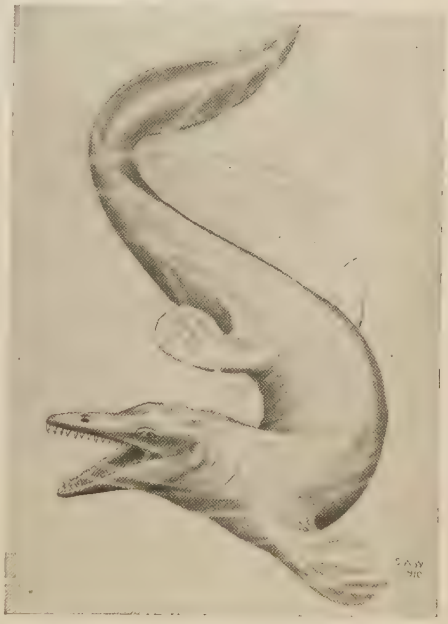


Fig. 496. — A scaled Cretaceous mosasaur (*Clidastes*). From Kansas. Restoration by Williston, from University of Chicago Press.

Birds. — In the early Cretaceous strata of Kansas are found from time to time most excellent skeletons of large reptilian water birds of a species which Marsh called the "regal western bird" (*Hesperornis regalis*, Figs. 490 and 497). The skeleton of this bird measures 6 feet in length, though it did not stand higher than 4 feet; its wings were rudimentary and of no use in air or water, but the great feet were webbed and paddled in the sea with outward lateral instead of downward strokes. Associated with these are found very rarely other much smaller birds with powerful wings

(*Ichthyornis*, Fig. 490). Both of these birds, like those of the Jurassic, had small curved teeth and were flesh feeders.

Mammalia. — Many jaws of diverse kinds of mammals have been found in the very latest Cretaceous deposits (Lance) of

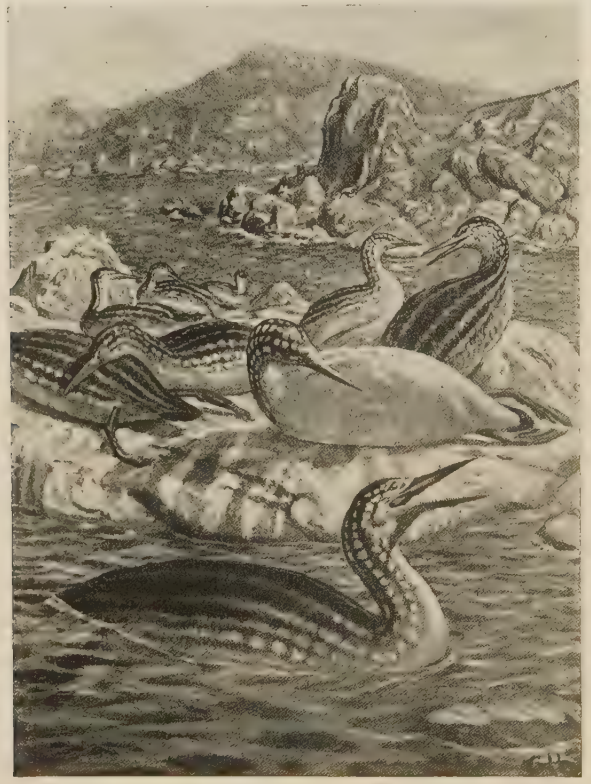


Fig. 497. — Swimming reptilian bird (*Hesperornis regalis*) from the Cretaceous of Kansas. Restoration by Gerhard Heilmann. See also Fig. 490.

Wyoming and Montana, and yet they seem not to have played an important rôle among the land animals of their time; nearly all were still small and of archaic character.

Great Mortality of Cretaceous Time. — We have learned that early in Cretaceous time the oceans began to spread over the continents, and that this transgression was one of the greatest of the geologic past. It therefore is interesting to note that even though there was great opportunity for expansive evolution, but few new marine stocks appeared. On the contrary, it was rather a time of death to many characteristic ones. Entire races of specialized

forms vanished, just as other stocks did at the close of the Paleozoic. In late Cretaceous times it was the ammonids, belemnids, rudistids, and other stocks of molluscs which disappeared. In addition, there was a great reduction among the reef corals, the replacing of the dominant ganoids by the teleosts or bony fishes, and, finally, the complete dying out of the various stocks of marine saurians.

On the land, with the establishing of the highest or flowering plants, we see the vanishing of the dragons or pterodactyls, and, at the very close of the Cretaceous, the last of the dinosaurs and the birds with teeth. In the sea the reptiles were displaced by the teleost fishes; on the land they were overwhelmed by the rise of the mammals; in the air they yielded to the more finely organized birds — in short, the reptilian dominance was destroyed with the end of the Mesozoic era, during which entire time they had been the characteristic animals of the sea and even more of the land.

Economic Products

Coal. — Just as the Pennsylvanian, at the close of the Paleozoic in eastern North America, was the period of greatest coal making, so was the Cretaceous in the Rocky Mountains country at the close of the Mesozoic (see Fig. 438). Some coal was laid down in all of the formations of the Cretaceous, but most of it in the closing time of the period. It is coal formed *in situ*, in local swamps ranging from Arizona into Canada, and occurs in both thin and thick beds (even up to 86 feet), and, as in the Pennsylvanian, usually in many superposed beds. Throughout the Rocky Mountains of the United States there are more than 100,000 square miles of coal-bearing lands, and Colorado alone is estimated to have 34,000,000,000 tons of available coal, most of which is of Cretaceous age. These coals range in grade from lignite to anthracite.

CHAPTER LII

THE DAWN OF THE RECENT IN CENOZOIC TIME

Cenozoic Era

Terminology. — During the rise of the science of Geology, the youngest era in the history of the earth was named *Tertiary* by Cuvier and Brongniart (see page 811), it being thought that all earlier time was comprised in but two other eras. Later came into use the term *Quaternary*, which included the youngest geologic formations of more or less unconsolidated materials scattered over the surface of the earth. This classification arose in western Europe, and was especially based on the sequence in the Paris basin of France. Here the marine formations are interbedded with continental deposits and therefore these two usually independent records, one of the oceans and the other of the lands, are checks upon each other. The shells of the marine formations were studied by Lamarck (1818–1822) and Deshayes (1824–1837), the mammals by Cuvier (1812), and the plants by Brongniart (1822–1828). Deshayes recognized nearly five thousand kinds of shells and the study of these led him to see that the youngest strata had the greatest number of still living species, while the forms found in the oldest rocks had the least faunal resemblance to those of the present. This change or evolution among the shells was taken by Charles Lyell (Fig. 498) in 1832 as the basis for dividing the Tertiary formations into *Pliocene* (from the Greek words meaning *more recent*, 35 to 50 per cent of the species still living), *Miocene* (*less recent*, 17 per cent still living), and *Eocene* (*dawn of the recent*, 3.5 per cent still living). To these Lyell later added *Pleistocene* (*most recent*,

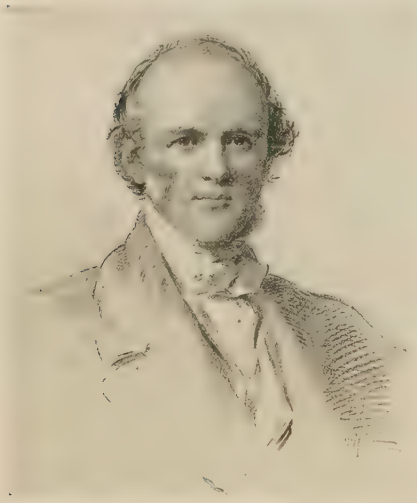


Fig. 498. — Sir Charles Lyell (1797–1875). Author of *Principles of Geology*.

90 to 95 per cent still living); and in 1854 Beyrich separated out the older Miocene formations under the term *Oligocene* (*little of the recent*). Finally Schimper (1874) showed that the very oldest Tertiary strata should be distinguished as *Paleocene* or *old Eocene*. A wider knowledge of the marine Tertiary molluscs has shown that this classification has permanent value, but that the percentage of living species is about as follows (see also page 442):

Quaternary		Pleistocene,	from 90 to 100 per cent of living Mollusca
Tertiary	Neogene	Pliocene,	" 50 to 90 " " " " "
		Miocene,	" 20 to 40 " " " " "
	Paleogene	Oligocene,	" 10 to 15 " " " " "
		Eocene,	" 1 to 5 " " " " "
		Paleocene, practically no living Mollusca	

Stratigraphic Relations to Mesozoic. — Everywhere the marine Tertiary is easily distinguished from the Mesozoic or older strata because of marked unconformities or disconformities that represent a long break in sedimentation, as is indicated by the marked differences in the faunas of the Cretaceous and Eocene formations. However, in places where Paleocene formations of fresh-water origin repose upon other continental deposits of late Cretaceous age, the separation is often very difficult to make, and this is at present the case in the Rocky Mountains area (see page 894).

Degree of Consolidation of Strata. — Where the Cenozoic strata have not been deformed, they are apt to be unconsolidated and soft, as in the marine formations along the Atlantic border and in the continental deposits of the Rocky Mountains. Along the Pacific coast, however, nearly all of the formations older than the Pleistocene are folded or otherwise altered so that they are as much consolidated as are the formations of the Paleozoic.

Life Characteristics. — The life of the oceans and the continents during Cenozoic time gradually evolved into that of the present day. This is especially true for the land animals but is less so for the land floras, since the latter had already taken on the expression of the Recent during the Cretaceous, as explained on page 904. The grasses became ever more prominent during the Tertiary and took possession of the open plains in the Miocene, leading to a general change in the evolution of the herbivorous mammals. The palms, of Cretaceous origin, became common throughout the world during the first half of Tertiary time, but of the once world-wide sequoias only two species are still living in isolated areas in California. The magnificent dinosaur development and the wonderful flying dragons or pterosaurs of the Mesozoic were gone, and all of the more

characteristic reptiles of the sea (ichthyosaurs, plesiosaurs, mosasaurs, see page 907) were wanting in the Tertiary. With the Eocene came the rise of the modern mammals, the most striking change in the life of the Tertiary, and their wonderful evolution and expansion over the continents will be described in Chapter LIII.

The reptilian toothed birds vanished with the Cretaceous, most of the living families of birds taking their rise in the Eocene. Here there was a more advanced and also a more varied bird life, a conspicuous element in it being large flightless forms resembling ostriches.

In the Eocene and Oligocene, large crocodiles were still common, and a great variety of turtles as well. Snakes and lizards of Mesozoic origin were more abundant in the Tertiary, and at that time arose the venomous snakes.

Among the insects, the most fundamental changes took place in the Permian, but the modern types originated in large part in the earlier half of the Mesozoic, although the butterflies were of Tertiary origin. More than six thousand species of Cenozoic insects are known, and it may be said that the fullness of insect life was attained in the Miocene. About Florissant, Colorado, there was a lake in Miocene time, surrounded by active explosive volcanoes. The ashes from these volcanoes fell into the waters, entombing the flora and countless numbers of insects, chiefly beetles, more than one thousand kinds being known.

The invertebrate life of the Tertiary marine waters was practically the same as that of to-day, though it should be said that it took on more and more of the Recent development during this era. Of the grand array of Mesozoic ammonites, not one species lived over into the Cenozoic, and the same is almost true of the belemnids.

While the corals were of modern types, they appear to have been no more conspicuous than they are now. The bivalves were particularly common and modern, and prominent among them were the many kinds with large siphons, the shell being buried in the mud. Oysters attained their climax of development in the Miocene of California, where the giants had a length of 13 inches, a width of 8 inches, and a depth of 6 inches. Finally, attention should be directed to the crabs, which were common in the Oligocene and Miocene. In the later Eocene occurred the first mammal adaptation to an oceanic life, in the form of whale-like animals (*Zeuglodon*). In the Oligocene came that of the sea-cows, and in the Miocene, that of the true whales, seals, and sea-lions.

Climate. — In early Tertiary time the climate, as shown chiefly by the plants, was marked by belts of temperature slightly cooler than during either the preceding Cretaceous or the succeeding Oligocene, when the temperatures were warm and equable throughout the world. With the Miocene, another reduction of temperature developed, probably due to the rising of the mountains, the foundering of parts of Eria permitting the colder Arctic waters to enter the Atlantic and

thus to cool this ocean. The climate continued to grow cooler to the close of the Pliocene, and in the Pleistocene occurred one of the two most marked glacial climates known to geologists, described in Chapter LIV.

Eocene Tillites of Colorado. — Professor Atwood in 1913 discovered at a number of localities in the San Juan Mountains of Colorado beds of tillite, ranging in thickness from 80 to 100 feet. The material was derived from high mountains fully 40 miles away, which then stood to the south and southeast of the present till areas. The tillites unconformably overlie the Cretaceous and are covered by Eocene tuffs, indicating a probable early Eocene age. It is to be expected that other areas of these tills will be found, in which event it will appear that the Laramide mountains were then widely covered by alpine and piedmont glaciers.

Areas of Sedimentation

The seas of Cenozoic time in North America were typically marginal overlaps of the oceans, and were of the nature of epicontinental or shelf seas. There were no inland or epeiric seas, in contrast to their dominancy during the Paleozoic and less markedly during the Mesozoic. The marine overlaps oscillated back and forth repeatedly and variably in the different areas of invasion, but at no time was more than 6 per cent (Middle Eocene) of the present area of North America under water, while the average for the Tertiary was about 3 per cent or even less. If, however, we include Central America and the Antilles, the total percentage may rise to 10 per cent, with the time of most marked flooding during the Oligocene epoch (Pl. 38).

In Europe and Asia, though the marine overlaps were also less extensive than during the earlier eras, Tethys continued in full extent from western Europe into the Malay region and attained its greatest spread in Oligocene time. Its connections with the Atlantic were limited, and for a time it had Arctic connections east of the Urals. The Alps of southern Europe and the Himalayas of India began to rise in the Miocene and then the eastern half of this extensive middle ocean began to vanish more and more. In the Pliocene, Tethys had attained about the area and the general configuration of the present Mediterranean; but in these alterations the remaining areas of former shallow seas had been changed to a chain of great basins of oceanic depths — an epeiric sea had given way to a mediterranean ocean.

In southern Europe, northern Africa, and Asia Minor the stratigraphic and tectonic history is that of Tethys; in eastern Asia, Melanesia and Australasia, the very intricate record is that of the Pacific. In North America there were marginal pulsations of the Atlantic, the Gulf of Mexico, and the Caribbean, but along the Pacific the history is more in harmony with that of eastern Asia.

Overlaps of the Atlantic Ocean

Cretaceous-Eocene Contacts. — Wherever the contact between the Cretaceous and the Eocene has been seen from New Jersey to central Mexico, Stephenson states that the Eocene sea advanced across a land surface which had reached an old or nearly base-leveled stage of erosion, as is shown by the almost horizontal contacts (see Figs. 491, 492). Of 168 species of Mollusca known in the highest Cretaceous of the Gulf region, not a single species passes into the Eocene.

Northern Atlantic Coastal Plain. — The Cenozoic deposits north of North Carolina (Cape Hatteras) are not at all as well developed as those in the states bordering the Gulf of Mexico, and no Eocene strata are present north of New Jersey. A limited Lower Eocene development of marine greensands and marls not over 225 feet thick occurs in Maryland, Delaware, and Virginia. Upon these follow, after a long interval of land conditions, the Chesapeake Miocene sands, clays, marls, and diatomaceous earth, with a thickness ranging up to 475 feet (see Pl. 38). The Chesapeake formation is of great significance because it has a cool-water fauna that is known to extend all the way from Massachusetts to Alabama, and it indicates that the old north land, Eria, was broken through by Middle Miocene time, permitting an Arctic current to descend along the east coast of North America (see Fig. 501).

Marine Pliocene strata are of very limited and occasional development. All of the Tertiary strata dip toward the Atlantic Ocean, and those of the Gulf States and of Mexico toward the Gulf.

Eastern Gulf Coastal Plain. — From Cape Hatteras southward and westward the marine Tertiary is well represented, with the longest sequence of the older strata in Alabama and Mississippi and of the younger ones in Florida. In the north, toward the old shore, it is a variable series of sands, greensands (glauconite), and marls, with more or less of lignite beds, while in Florida occurs an unequaled development of Oligocene and Miocene limestones and marls, with but little sand. The thicknesses are variable, often under a few hundred feet, and at best attain to over 2000 feet. In Florida the formations above the Eocene reach 2500 feet in depth, and in that state the Oligocene is profuse in invertebrate life. Florida appeared in late Oligocene time as a small island, and has been a peninsula since the Pliocene.

In the embayment of the Mississippi valley extending to southern Illinois occur only Eocene fresh- and brackish-water sands and clays,

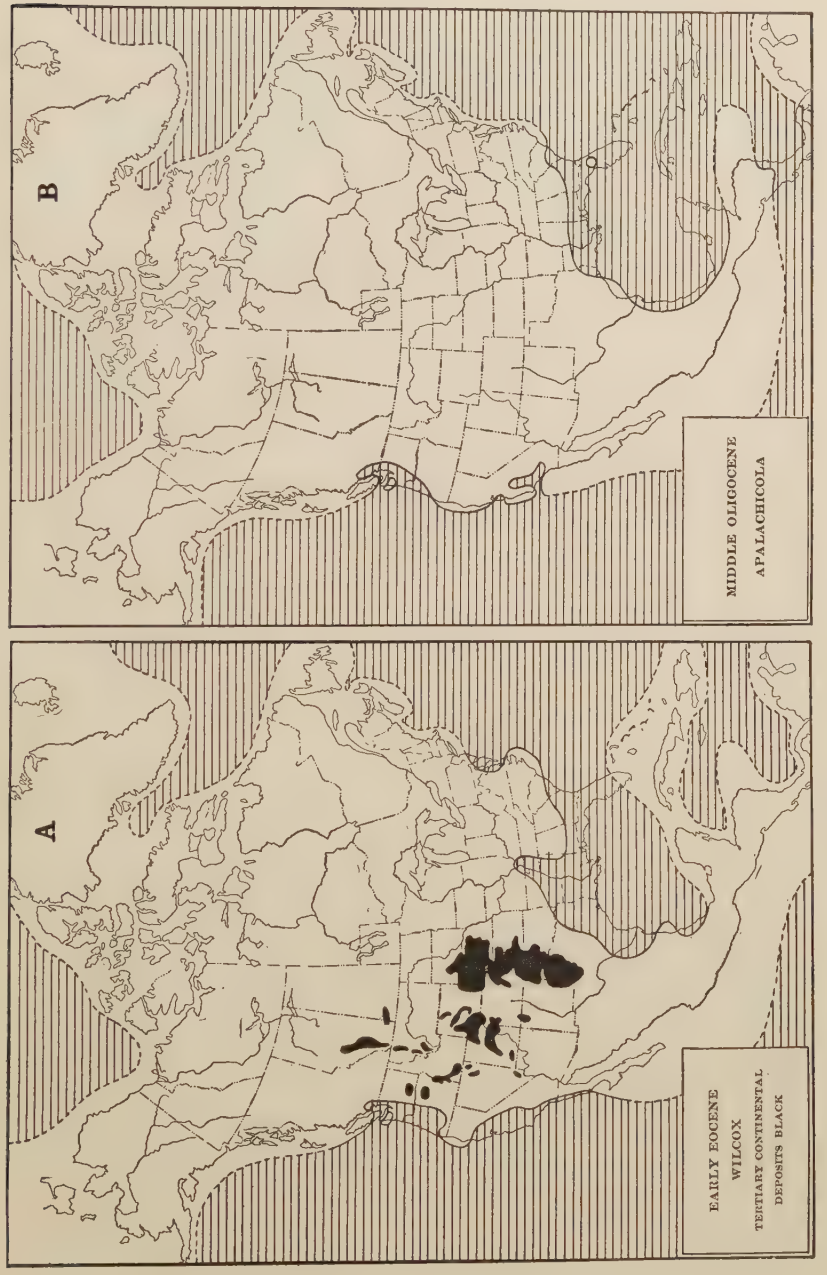


Plate 38. — Tertiary paleogeography.

with beds of lignite, the plant accumulations of former swamps. These are the sediments of the ancient delta of the Mississippi River when the shores of the Gulf of Mexico were at Cairo, Illinois. Later, in early Oligocene time, the sea had withdrawn to middle Alabama (see Pl. 38).

Western Gulf Coastal Plain. — Westward from the Mississippi River, the older Eocene is well developed into Texas and northern Mexico, while the younger Eocene is not known west of the Red River of Louisiana but is again sparingly present in northeastern Mexico. These marine, brackish-water, and swamp deposits of sands, clays, greensands, and lignite beds attain to a maximum thickness of 2000 feet. Since Oligocene time the great stream of fresh water from the Mississippi River has not only had its influence on the sedimentation of this area, but has also prevented the intermigration of the shallow-water life to the east and west of the river.

The Oligocene formations are well developed in Louisiana, where they are essentially fresh-water sands and green clays, reaching a thickness of 1600 feet. In Texas these strata are practically unknown, but in Mexico they occur as narrow overlaps. West of the Mississippi River Miocene strata are known only in deep wells, and at Galveston, Texas, they are 2300 feet beneath the surface, showing the extent to which the eastern margin has been warped beneath the sea since late Miocene time. Of Pliocene strata there is but a small development in Mexico. (See Pl. 38.)

Petroleum of the Gulf Field. — In Tertiary strata of the Coastal Plain in the states of Louisiana and Texas occur a number of scattered, small, circular areas that yield in abundance heavy asphaltic and sulphurous oils (see Fig. 383). It is thought that there are here deep-seated bathyliths that deflect upward hot waters which dissolve out the disseminated salts of the lower beds. Ascending, the waters cool, crystallizing out the salts, which form concretionary rising plugs bulging the higher beds into domes, and in these local arches the oil rises and accumulates. (Harris.) (See Fig. 499.)

Central America. — There are no marine deposits of the early Eocene known in Central America, and hence we may assume that at that time and during the late Cretaceous North America and South America were united by a land bridge wider than the present one. This connection permitted the land life of the two continents to intermigrate. During later Eocene time, however, and more especially throughout the Oligocene, the Caribbean Sea spread widely across southern Central America and some of the Atlantic Eocene molluscs migrated to California. In Miocene time the two continents were again united, but even though the Central American land was wide,

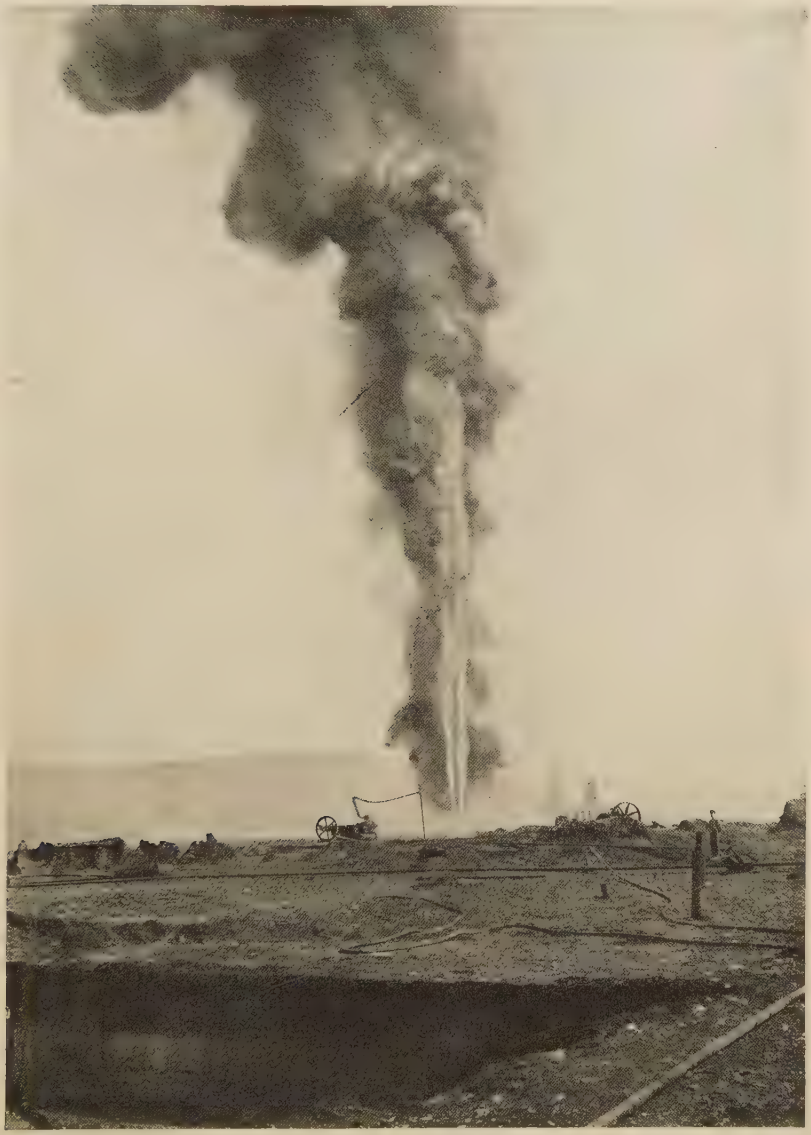


Fig. 499. — Burning oil fountain, 330 feet high, in Miocene strata at Baku, Russia. In 1897 this well was yielding, through a 12-inch pipe, 90,000 barrels of petroleum per day.

the land bridge does not appear to have been a favorable one for intercontinental migration of land animals. This may have been due to the mountainous and volcanic nature of the region, but more probably to the barrier of the tropical jungle. The Caribbean did not again invade this land until Pliocene time, and then only marginally. (See Pl. 38.)

Antillian Region. — The Greater Antilles, Cuba, San Domingo, and Porto Rico appear to have been large land areas during the Eocene, and it further seems that Cuba was then connected with Central America. In the Oligocene, however, all except the mountainous central portions of these islands were beneath the sea, whose waters were tropical and abounded in a very varied life. The record begins with local shallow-water formations of dark to black shales and ferruginous sandstones up to 1000 feet thick. These are followed by the widely spread white foraminiferal limestones and marls varying in depth from 700 to 2600 feet. From this it appears that it was during the Oligocene that the oceans most widely flooded the Antilles and Central America.

Elevation of the Antilles again took place early in the Miocene, but it is not yet established that Cuba was then or at any time subsequently in connection with Central America. The living native mammals of the Antilles are small, of but a few kinds, and of ancient types. None of the larger North or Central American mammals appear to have reached these islands. In the Pleistocene of Cuba, however, there are several species of ground-sloths that Matthew states are all derived from a single small form thought to have drifted there on a natural raft across the Caribbean from South America.

Overlaps of the Pacific Ocean

Almost all of our knowledge of marine Cenozoic invasions along the Pacific is restricted to the states of California, Oregon, and Washington, and northward into the Vancouver area of Canada. There appears to be no sedimentary record along the shores of British Columbia and Alaska until late in Miocene times, and even this marine overlap was of small extent (see Pl. 38).

In most places the Cenozoic rests unconformably upon the Mesozoic or older rocks, though at times the contact is a disconformable one. In California there is another unconformity in the Miocene. Arnold states that about 25,000 feet of strata were accumulated during the Cenozoic, but if we take the maximum thicknesses for all the formations the total rises to about 45,000 feet. In the main the deposits are coarse detritals, as sands, muds, and much volcanic ash with local lava flows. The seas were shallow and in places became filled with sediment and then passed into marshes, making coal beds, as was especially the case in the estuary of the Puget Sound region, where 125 coal beds occur. The times of most marked and general sedimentation were in the early Eocene (8000 to 12,000 feet) and the

late Miocene (8000 feet in California). In the Pliocene and Pleistocene, 13,000 feet of sands and volcanic materials were laid down south of San Francisco.

Throughout Alaska and extending into Mackenzie and British Columbia occurs the wide-spread Kenai formation of continental character, which has a maximum thickness of 10,000 feet. It has much plant material and many beds of lignite, with some marine animals that indicate the age to be Eocene.

It is not yet clear to what extent during the Cenozoic Alaska was united with Siberia, though it seems that the ocean did not invade the Bering Strait region until late in Miocene times. If this land bridge between Asia and America was not in continuance throughout all of this time, it was during most of the era. Since the Pliocene the bridge has been crossed by the sea at different times, though at no time was this very shallow sea much deeper than it is now.

Petroleum in California. — California is now the leading oil-producing territory in North America, the yield being 38 per cent of the total amount produced by the United States (see Fig. 383). The total acreage is not over 125,000, and in 1914 there were more than 5800 producing wells, with a depth of from 200 to 5700 feet. The petroleum is from more or less decidedly deformed strata ranging in age from Cretaceous to Pliocene, and the oils are mainly asphaltic, though lighter ones also occur. (Arnold.) (See Fig. 499.)

Continental Deposits of the Rocky Mountains

Fresh-water and eolian deposits of Tertiary time cover great areas in the United States, chiefly in the foothills and the plains country east of the Rocky Mountains (see Pl. 38, Fig. A). It should be clearly understood, however, that the deposits consist of a large number of separated formations, laid down by many large and small rivers over their flood plains, now here and now there throughout the Tertiary. As a rule, the strata remain horizontal and are somewhat consolidated into sandstones, sandy shales, and local conglomerates. Volcanic ash in thick beds or reworked by water and wind occurs in most of the formations and constitutes a considerable amount of the Tertiary rocks of the plains country. Nearly everywhere the strata are exposed to view in more or less locally dissected places where the rain, streams, and wind of the present semiarid climate have worn them into those picturesque areas known as "bad-lands" (see Fig. 21). The thickness at any one place varies from a few hundred feet to several thousand but if all the thickest local deposits are combined the total Tertiary sedimentation attains to well over 20,000 feet. It is in this vast mass of material that lies buried the most interesting known record of mammalian evolution, the remains of one organic

dynasty after another, whose histories have attracted the attention of paleontologists the world over.

The older geologists stated that these strata had in the main been laid down in lakes of vast extent. During the past fifteen years, however, it has been shown that they are the materials of rivers originating in the mountains, and meandering and unloading over great flood plains under a more or less semiarid climate. In addition there is also a great deal of wind-borne material, desert dust, and fine volcanic ashes from the western volcanoes, that at times killed and buried the flora and fauna over considerable areas (see Fig. 506).

Paleocene. — During the quieter time between the Laramide Revolution toward the close of the Cretaceous and the renewed Eocene elevation were laid down the widely distributed Paleocene deposits (Fort Union, Puerco, Torrejon), with thicknesses ranging between 1000 and 2000 feet.

Eocene. — Then followed, in the west, uplift combined with much volcanic activity, causing the development, during the early Eocene, of intermontane formations (Wasatch, Wind River, Green River of shallow lake origin, and Bridger basins). These have thicknesses varying from 2400 to over 10,000 feet, the greater part of which consists of ash and coarse igneous detritals. In later Eocene times (represented by the Uinta basin) the formations are much thinner, averaging about 2000 feet. The Eocene has the best developed record of the Tertiary and its formations occur in western Wyoming, eastern Utah, and western Montana.

Oligocene. — In Oligocene time (White River formation, John Day basin of Oregon consisting largely of from 3000 to 4000 feet of volcanic ash and tuffs) there was little crustal disturbance throughout the Cordilleran region, and therefore the deposits do not as a rule average much above 500 feet in thickness. They are, however, of wider distribution than are the Eocene deposits, occurring in Nebraska, North and South Dakota, Wyoming, Colorado, and Montana. The formations consist of fine sands, sandy muds, and considerable fine ash derived from the far away western explosive volcanoes. There are also local thin limestones rich in fresh-water snails, the deposits of ponds and small lakes.

Miocene. — The general environment of the Oligocene was continued into the Miocene (Arikaree, Harrison, Lower Loup Fork, Clarendon, Deep River formations), with the difference that elevation was again going on west of the plains country in later Miocene time, along with a change to a cooler climate. There is also more ash present and the grain of the strata is coarser in the west and finer in the east. The thickness of the formations varies between 400 and 2300 feet, with the main areas of deposition in Nebraska, Kansas, and northeastern Colorado.

Pliocene. — The Pliocene formations (Upper Loup Fork, Blanco) are widely scattered, of limited extent, and not very well understood. The climate became more arid and much cooler and most of the larger mammals were exterminated.

Cascadian Revolution

North and Central America. — In the preceding chapter it was stated that the Mesozoic era in North America was closed by the Laramide Revolution, when the Laramide Mountains (practically the

Rocky Mountains) were folded and faulted toward the east (see page 900). During Paleocene time mountain making was not active in the area of the Laramides, but at the close of this epoch, folding, faulting and igneous activity were again very marked in Utah, western Wyoming, and Montana. Eruptions, mainly of an explosive character, then continued, though with diminishing force, throughout Eocene and Oligocene time, but the earth-shell remained fairly stable, enabling the atmospheric forces to reduce greatly the high elevations of the Laramide Mountains.

In Middle Miocene time the Pacific States were again in the throes of mountain making, and igneous eruptions became active, with the formation of high local mountains in eastern Washington and Oregon, and of the Coast Range of California (see Fig. 501). It is interesting to note here that the great earthquake rift of San Francisco which extends for more than 400 miles southeast into the Mohave desert had its origin at this time. Of active volcanic regions during the Miocene and Pliocene, there were eleven, extending interruptedly from southern Mexico into Alaska. In the basin of the Columbia River more than 200,000 square miles were covered by lava flows, ranging in depth up to 4000 feet, and this area is to-day the Columbia River Plateau (Fig. 482). A more scenic area of igneous rocks is the Yellowstone National Park, where the ashes and other material extruded from Miocene volcanoes buried forest after forest, and where many of the still vertical trees are changed to silica, though preserving their original microstructure (Fig. 500).

During the Miocene, decided folding and faulting with volcanic activity also occurred in the Isthmus of Tehuantepec of southern Mexico, in Central America, and apparently throughout the West Indian islands. Finally, it may be said that especially during the Miocene, and less in the Pliocene, the entire area of the overlaps of the Pacific Ocean in North America (see Fig. 482) was being elevated, folded, faulted, and thrust eastward into the Pacific system of mountains. During the Pliocene, the entire area of the Rocky Mountains and especially the plateau region of the Colorado River were further vertically elevated several thousand feet. With this elevation the Colorado River region began to cut its great gorge and since then has been developed what is now the grandest geologic exposure anywhere, the Grand Canyon of the Colorado (Fig. 349). With these wide-spread movements in the earth-shell also came into being those grand volcanoes that were still active throughout the Pleistocene: Rainier (14,526 feet above the sea), Shasta (14,380 feet, see Fig. 153), and Lassen's Peak (10,437 feet) of the Pacific States;

Popocatepetl (17,500 feet), Ixtaccihuatl (16,900 feet), and Orizaba (18,250 feet) of southern Mexico.

Eastern North America was also elevated at this time, but how much is not yet determined, and the entire Mississippi valley was

Fig. 500. — Miocene tree trunks of the Fossil Forest, Yellowstone Park, Wyoming. Photograph by J. P. Iddings, U. S. Geol. Surv.

raised several hundred feet, or to its present elevation. Generally speaking, the close of the Pliocene must be regarded as a time of great deformation, a critical period in North American geologic history.

South America. — Toward the close of the Cretaceous, the Andes had been elevated and folded throughout the length of South America (4500 miles), and during most of Tertiary time an extensive peneplain (in places it was a postmature surface) was being developed in the Central Andes. Vertical uplift began in later Tertiary time, elevating this peneplain from 3000 to 7000 feet. This was in turn eroded to mature slopes and then was rapidly warped in Pliocene and early Pleistocene time, so that now the deeply dissected erosion surface of the old peneplain stands at an average elevation of 12,000 feet, though locally it varies between 6000 and 15,000 feet. Upon it in the west rest immense lava flows and lofty volcanic cones, some of which attain a height of 21,000 feet above the sea. These are part of a great volcanic field whose development began in the early Tertiary and was completed soon after the Pliocene uplift began. The Central Andean plateau is the second highest in the world, being exceeded only by that of western Tibet to the north of the Himalayas of India, where the intermontane plains range from 14,000 to 17,000 feet above the sea. (Bowman.) (See Fig. 501.)

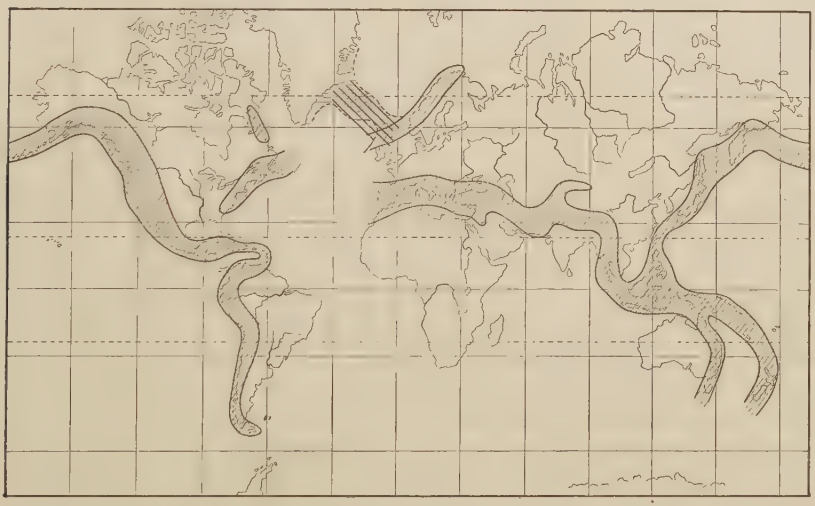


Fig. 501. — Areas of dominant folding and uplift (oblique shading) during the Tertiary. Horizontal shading, the fractured and down-sinking area of Eria; northwest-southeast lines, the general direction of fractures and dikes.

Greenland. — All Greenland and the region eastward across Norway, Sweden, and Finland (Fennoscandia) were subject to great block faultings or warpings previous to the Pliocene, developing not only great rifts or graben but broad sinking areas as well, with a general trend to the northwest and southeast. This was the time

when Eria was broken through, separating Laurentia from Baltica (Fig. 501). Previous to the Middle Miocene this land was the bridge that enabled the mammals of Europe and North America to intermigrate. Periodically, but more especially during the Oligocene and Miocene, lava flowed widely through fissures over all these lands, the Faroe Islands, Scotland, and western Ireland (Giant's Causeway). The foundering of the crust where the Norwegian sea now is, permitted the triumphant spread of the Atlantic into the Arctic Ocean.

Gondwana. — On page 880 it was stated that Africa was separated from South America late in Comanchian time (Fig. 488) and now we learn that late in the Eocene the remainder of this equatorial Atlantic bridge sank, since Eocene deposits are general along the western border of Africa. The Cretaceous remnants of Lemuria almost all sank beneath the Indian Ocean during the Tertiary.

Europe. — The majestic Alps of Europe are mute evidence of the great unrest of the earth's crust during the Cenozoic, their upward culmination taking place in Pliocene time. The movement began in the west late in the Oligocene, when the Pyrenees of Spain, the Rif Mountains of Morocco, and the Apennines of northern Italy had their origin. The entire Alpine system of western Europe began to rise early in the Miocene, and this deformation was most active late in the same epoch and was completed early in the Lower Pliocene when these mountains stood at their highest. The Eocene nummulitic limestones of the Alps are still found 10,000 feet above the sea, and those of the Pyrenees 11,000 feet. The movement was both vertical and thrusting from the south and southeast, from the southern portion of Tethys, elevating and folding the Tertiary and older strata of the northern areas of this mediterranean into overturned, recumbent, and nearly horizontal folds, and pushing the southern or Lepontine Alps about 60 miles to the northward into the Helvetic region. Erosion has since carved up these overthrust sheets, leaving remnants lying on foundations which belong to a more northern portion of the ancient sea. Most noted of these residuals of overthrust masses is the Matterhorn, a mighty mountain without roots, a stranger in a foreign geologic environment. The thrusting was felt as a warping as far northwest as London, for the basins of London and Paris date from this time. The Caucasus Mountains of eastern Europe, between the Crimea and the Caspian Sea, are also of early Pliocene origin, for their Miocene strata are now 6500 feet above the sea (see Fig. 501).

Himalayas of India. — During Eocene time Tethys continued unbroken across Asia Minor, northern India, and Burma into the

Indian Ocean and Melanesia. At the close of the Eocene, however, all of the Tethyian area of the Himalayas and Burma began to fold, giving rise to mountains of considerable altitude in many regions, and yet not extensive enough to blot out the sea. During the Oligocene, Tethys, even though shallow, still preserved its continuity, accumulating thick, uniform, marine deposits of gray to greenish shales and calcareous sandstones (Flysch of Swiss geologists). Toward the close of the Middle Miocene, the second and more marked phase of folding began, changing Tethys into a series of disconnected but subsiding basins, accumulating the continental deposits known as the Siwalik clays, sandstones, and conglomerates. Finally, in the Pliocene, came the third and greatest upheaval, when the Himalayas, the loftiest mountains of the earth, had peaks nearly as high as Mt. Everest of the present, which stands 29,002 feet above the sea. The nummulitic limestones of Eocene age are even now as high as 19,000 feet above sea-level, and once extended higher over the mountain axes. This uplift affected the land to the north for 1400 miles into Tibet and Mongolia, and the thrust pushed the older rocks over the newer ones in a north to south direction. (Vredenburg.) (See Fig. 501.)

Summary. — In North America the deformation of the Laramide Revolution was renewed in the early Eocene, followed by a long, almost quiescent time up to the close of the Oligocene. Then unrest made its appearance in the western area of Tethys, and throughout the later half of Miocene and Pliocene time mountain making was going on in most parts of the world, in many areas on a stupendous scale. North and South America with their longitudinal chains of mountains did not change much in outline during the Tertiary, but Europe, Asia, the Antilles, and Central America, with their latitudinal foldings, underwent marked alteration, and it was in fact in the Pliocene that these continents took on their modern expression. Finally in the Pleistocene the greater part of the Pacific Ocean was margined by majestic volcanoes.

The Cascadian Revolution of western North America has been of long duration, beginning in the Middle Miocene and continuing into the present time. It is marked by intermittent action, pulsations of folding, thrusting, and igneous activity, resulting in new mountain systems, increasing relief, and a higher continent. To us it now appears as if interrupted and finished, because we see it in near perspective. In its entirety, however, it is one of the greater revolutions of the earth, and there is no proof that the end has yet been attained. Long ago Le Conte said that the Cascadian Revolution is

so recent that the record of it is not lost, and a study of it enables us better to comprehend the changes wrought by the earlier revolutions. In the geologic future it will take its place in the earth record through the evidence of its great foldings, metamorphism, and wide erosion of the older record — a transformation comparable to that wrought by the Appalachian Revolution closing the Paleozoic.

The closing revolution of the Tertiary era was a critical period in the history of the earth, and as it culminated in the Pleistocene glacial climate, the conditions were all the more hazardous for the organisms that inhabited the polar and temperate regions of the earth. The warmer parts of the globe were the asylums that repeopled the northern lands, but man, probably arising in Asia, advanced from the savage to the civilized state under the influence of cooler and even glacial climates. We are now living in a time of rugged lands, obliteration of ancient peneplains, cold polar climates, and marked temperature belts.

CHAPTER LIII

THE EVOLUTION OF MAMMALS AND THE RISE OF MENTALITY

Origin of Mammals. — The lands of Cenozoic time were dominated by mammals, and the seas and oceans of this era were not devoid of them. Mammals were, in fact, as characteristic of the Cenozoic as reptiles were of the Mesozoic. It is, however, true that mammals originated as early as the Triassic, but at no time in the Mesozoic era did these small animals take the lead among organisms.

It was pointed out on page 810 that the mammals had their origin in reptiles (Theriodontia) that lived during Permian and Triassic times. These were long-limbed quadrupedal forms with a mammal-like skull and teeth, and among them were insect-eating types that are thought to have given rise to the egg-laying mammals. These small reptilian mammals first appeared in the Triassic, but though they lived throughout the Mesozoic, little is known of them. In fact, our knowledge is almost restricted to lower jaws and isolated teeth and it is not until we reach the Cenozoic that skeletons become sufficiently abundant to determine their structure and their genealogies. This higher mammalian succession is a wonderful series of evolutions, and if the student wishes to follow it out in more detail than can be given here, he is referred to Scott's *A History of Land Mammals in the Western Hemisphere* and Osborn's *The Age of Mammals.*

Definition of Mammals. — Mammals, structurally the highest group of animals, are warm-blooded vertebrates with glands that secrete milk when the females are nursing young. These glands, which vary in number from one to eleven pairs, are the mammary glands or breasts, the structures from which the class has taken its name, for *mamma* means *breast.* They are also present in the males, but are rudimentary and normally non-functional. All mammals are more or less covered with hair and these growths of the skin are as characteristic of mammals as feathers are of birds.

With regard to the nervous system, the brain in mammals attains the highest degree of development known, and is most markedly convoluted in man. The body cavity differs from that of all other

vertebrates in that it is completely divided into two parts by a muscular membrane, the diaphragm, which separates it into a thoracic cavity containing the heart and lungs, and an abdominal cavity containing the remaining viscera. In most mammals there are two sets of teeth, the milk dentition or temporary teeth which eventually fall out, and the permanent teeth which succeed them. The heart is four-chambered as in the other class of warm-blooded animals, the birds, and the course of the blood through it is the same in both. The period of fœtal development or gestation varies from three weeks in some mice to twenty months in the elephant.

Most mammals have a completely terrestrial habitat, while the seals, sea-lions, sea-cows, whales, and porpoises live in the oceans. One order of wide distribution, the bats, have developed the front limbs into wings, while other stocks have lateral or body membranes between the limbs, and spreading these, glide from tree to tree.

Classification. — There are living more than seven thousand kinds of mammals, and in North America alone there are more than twenty-one hundred species. Of fossil mammals there are several thousand additional kinds. All these are separated into two subclasses on the basis of the development of the young. In the most primitive mammals, the *Prototheria*, the young are not born alive but are hatched from eggs as in reptiles and birds. Of this ancient stock there are but few living representatives, among them the duck-billed mole (*Ornithorhynchus*) and the spiny ant-eater (*Echidna*) of Australasia. These were once distributed all over the world, particularly in Mesozoic time (Protodonta).

In the other subclass, the *Eutheria*, the animals are viviparous, and the group includes nearly all the living mammals as well as those of Cenozoic time. The marsupial mammals (Didelphia) or animals with an abdominal pouch are the more ancient and primitive, though more advanced than the egg-laying Prototheria. In nearly all of them there is no placenta (see page 807). The young are born in an immature state and are then attached by the mother to the breasts in the marsupium, where they complete their development. They had their origin early in the Mesozoic (Allotheria, also known as Multituberculata), were widely distributed throughout the world, and died out with the Paleocene. Out of these little animals arose other marsupials, probably as early as the Jurassic, and it is thought that they in turn gave rise to the living forms. The marsupials are still in full development only in the ancient organic asylum, Australasia, though the opossums are common to North and South America.

By far the greatest number of living and Cenozoic mammals are the placental forms (Monodelphia). The placenta is a special growth, partly of fœtal and partly of maternal origin, by means of which the embryos are attached to the mother and nourished during the period of gestation; the young are born in a relatively mature state. The placental mammals appear not to have arisen in the marsupials, but to have had an independent origin in the egg-laying forms (Prototheria) during the Mesozoic.

There are at least twenty-seven orders of placental mammals, and of these but sixteen have living representatives, the others having originated in and died out with the Cenozoic. Among the *clawed mammals* (Unguiculata) the more con-

spicuous orders are the Carnivora or beasts of prey (wolves, bears, cats, seals, walruses); Rodentia or rodents, the gnawing mammals (hares, rabbits, squirrels, beavers, rats, mice, porcupines); Chiroptera or bats; Edentata or sloths and armadillos; and Insectivora or insect-eaters (moles, hedgehogs, shrews). The *mammals with nails* include but one order, the Primates, such as the lemurs (Lemuroidea), and the monkeys, apes, and man (Anthropoidea). The *hoofed mammals* (Ungulata) are very varied, and among them may be mentioned the even-toed forms (Artiodactyla), such as the swine, camels, deer, antelopes, sheep, oxen; the odd-toed forms (Perissodactyla), such as the horses, tapirs, rhinoceroses; the trunk-bearers (Proboscidea), the elephants and mastodons; and the Sirenia or sea-cows and dugongs. Mammals wholly adapted to the oceans and therefore greatly altered in form so as to resemble fishes are known collectively as Cetacea (whales, dolphins, porpoises).

Increase in Size of Brain. — Lartet suggested in 1858 and Marsh demonstrated in 1874 and again in 1885 that the brain in mammals increased in size throughout the Cenozoic, and that the enlargement was by far the most striking in the upper lobes or cerebrum. In the Eocene the brain was about one eighth that of living forms of the same stocks.

Mammal Succession in North America

The Tertiary of North America opens with an archaic indigenous mammal fauna, a most curious, strange, and bizarre assemblage. It is plain that it is an advanced and diversified fauna, the descendants of Mesozoic mammals. Later appear unheralded as migrants the modern mammals, and their introduction sounds the death knell of the archaic forms, for one stock after another vanishes and most of them are gone before the close of the Eocene, though the ancient flesh-eaters (creodonts) continue into the Oligocene. Where the modern mammals originated is not yet known, though it is usually assumed that Asia was their birthplace.

Paleocene Mammals. — The North American Paleocene mammals were all archaic, that is, they were very primitive, generalized, omnivorous or fruit-eating, dominantly placental, and small. None of them were as large as a sheep, the limbs were short, with five digits each, the tails were long and heavy, and the brains extremely small. They were closely related to one another and appear to have been the direct descendants of the Mesozoic mammals continued with some change into the Cenozoic. There were among them no known representatives of the primates, rodents, carnivores, or of the even-toed and odd-toed hoofed mammals. Of modern orders, only the insectivores and marsupials were represented.

Lower Eocene Mammals. — The most striking feature of the life of early Eocene time (Wasatch-Wind River) was the appearance in

considerable numbers, both in western Europe and in North America, of the first representatives of the progressive or modernized mammals. Among them were diminutive horse-like forms (*Eohippus*), fleet-footed rhinoceroses, tapirs without a proboscis, the first ruminants and pig-like forms, squirrel-like rodents, insectivores reminding one of the European hedgehogs, carnivores, lemurs, monkeys, and probably also marsupial opossums. It was in the main the mammalian life of a mountainous country, superior in foot and tooth structure to the indigenous archaic fauna, and of a higher intelligence. In the struggle for existence the archaic mammals were the losers (58 per cent present in the Wasatch) and before the close of the Lower Eocene their number was far less (Wind River, 37 per cent).

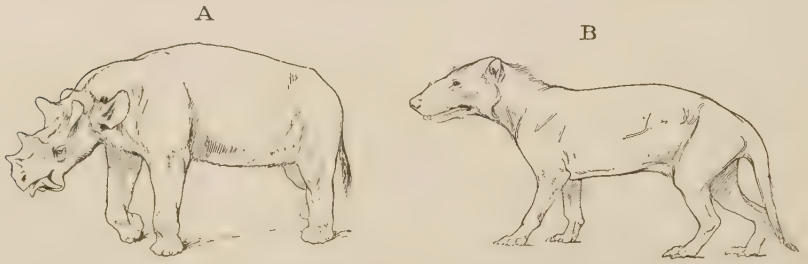


Fig. 502. — *A*, large hoofed uintathere (*Uintatherium alticeps*) of the Eocene (Bridger). From Scott's *History of Land Mammals*. *B*, the last creodont (*Hyænodon*) of the Oligocene. From Osborn's *Age of Mammals*.

Middle and Upper Eocene Mammals. — In the great abundance of mammals in the later Eocene there was no evidence of new migrants having come from Asia or Europe, but the fauna was dominantly that of the older Eocene with a small proportion of archaic forms (Bridger, 20 per cent; Uinta, 13 per cent), continued with persistent and divergent evolution. The changes were largely toward greater size, more muscular power, and the origination of new indigenous forms. There were many hoofed animals and all were browsers. This was again an upland or mountainous mammal assemblage, on the whole well balanced, with an equal distribution of arboreal, running, aquatic, burrowing, carnivorous, and herbivorous types.

During the later Eocene appeared tiny camels, true tapirs, oreodonts (an extinct group of ruminating hogs peculiar to America, Fig. 506), giant pigs or entelodonts (Fig. 504), armadillo-like animals with leathery shields, and primitive dog-like forms. In addition there were many hoofed forms, as titanotheres (Fig. 503) and the very characteristic gigantic uintatheres (Fig. 502 *A*) — mammals unlike anything now living — and fleet-footed rhinoceroses. The archaic

flesh-eating creodonts were still present (Fig. 502 *B*). Marsupials were represented by the opossums, and the lemurs and monkeys were still common, though representing the last of the primates in North America.

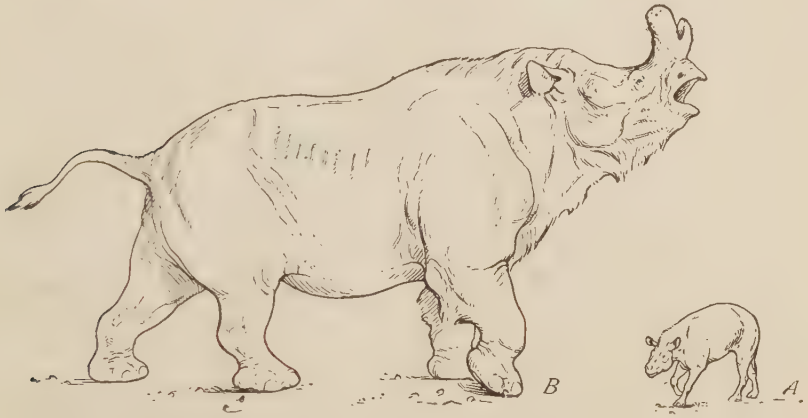


Fig. 503. — Titanotheres. *A*, first stage in the evolution (*Eotitanops* of the Wind River). *B*, last known stage (*Brontotherium* of the White River). After Osborn.

Oligocene Mammals. — It was during the Oligocene that mammals for the first time took on a modern aspect, for here nearly all were progressive forms. We now begin to get representatives also of still existing families, and of such there were six of rodents, four of carnivores, and one of odd-toed hoofed mammals. Then in this period we get our first knowledge of the varied mammalian life of the open plains and of grazing mammals, indicating that the grasses were taking possession of the open country.

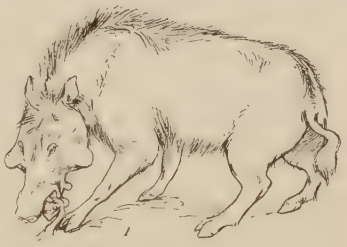


Fig. 504. — One of the giant pigs or entelodonts (*Archæotherium*) of the Oligocene (White River). From Scott's *History of Land Mammals*.

Early in the Oligocene took place a second and more marked invasion from Europe. The interchange was considerable, yet it was not complete and the time of migration was of short duration. Europe lost its horses early in the Oligocene, but in North America there was continued evolution of the three-toed forms. The camels were also better represented (Fig. 507), and among them were grazers, these and other hoofed mammals being present in bewildering variety. The tapirs were not common, but of rhinoceroses there were many, some fleet of foot, some stocky, heavy and amphibious in habit, and of the true rhinoceroses there were forms with and without horns.

Rodents were also common, such as beavers, squirrels, pocket gophers, mice, and hares. Among the ruminants, peccaries were numerous, the entelodonts were of large size (Fig. 504), and the oreodonts, not unlike the peccaries and wild boars in appearance and size, were exceedingly abundant, varied, and ran in great herds (Fig. 506). Among the carnivores, small dogs were remarkably abundant and diversified, in fact, more so than ever before or since. The last of the archaic creodonts occurred here (Fig. 502 *B*) and as they vanished their place was taken by dogs and later by wolves and the first sabre-tooth cats; true cats, however, were not yet present.

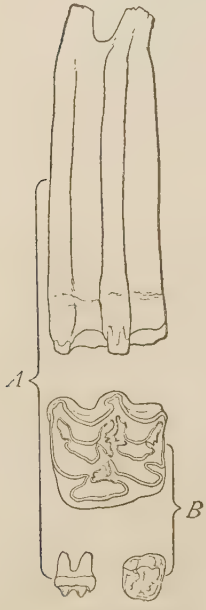


Fig. 505. — Grinding and grazing teeth. Below, grinding teeth of the "dawn horse" (*Eohippus*); above, grazing teeth of the living horse (*Equus*). Drawn to scale, to show the increase in complexity, length (*A*), and width (*B*). From Osborn's *Age of Mammals*.

Miocene Mammals. — Miocene mammals are replete with interest because of the changes wrought in them and in the floras by the alteration in climate to cooler and semiarid conditions. Great chains of mountains were being elevated, Eria was being torn apart (see page 923), and these derangements in the topography and geography had their effects not only on the climate and life, but on the migrations of the mammals as well. The Miocene, and especially the later Miocene, was therefore characterized by an increase of grassy plains, though this statement is not based on the presence of fossil grasses but is deduced from the change that took place during this period in the mammalian teeth from those of the browsing type to the grinding or grazing kinds (Fig. 505). There were now large numbers of horses, camels, ruminants, and rodents with high-crowned, persistently growing, grinding teeth. On account of the silica which the grasses contain, they are very abrasive and rapidly wear the teeth down.

The third marked migration of mammals into North America took place in the Middle Miocene and the migrants came from Asia by way of the Siberia-Alaska bridge. The most conspicuous among them were the four-tusked, browsing, long-faced mastodons, the short-legged rhinoceroses, the cats, and the beavers.

Prominent among the Miocene mammals were the horses, which roamed the plains in great herds. All were three-toed and at first all

were still browsers, but in the later Miocene the grazing type predominated. Camels were also plentiful. Rhinoceroses were present in great variety, some hornless, others with a single horn on the end of the nose, and still others with an additional horn on the forehead. The commonest type were extremely heavy, with very short legs (*Teleoceras*); others were long in the legs and less massive in body.

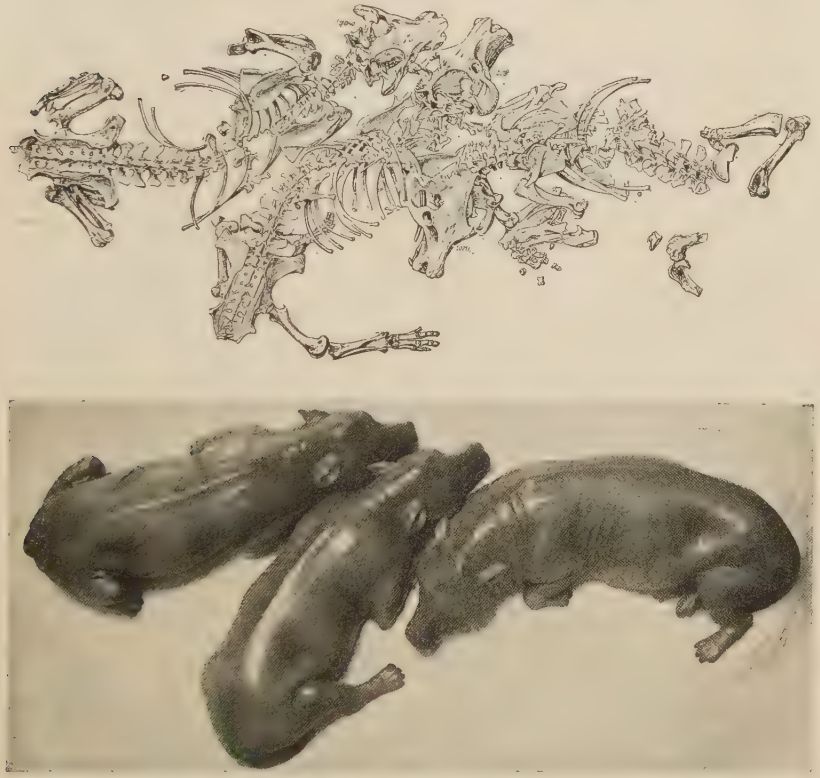


Fig. 506. — A remarkable group of three Miocene oreodonts (*Promerycochœrus carrikeri*). Above are the skeletons as found in the rocks (note how they are huddled together, having met death in this attitude), and below, the animals restored in the flesh. Found by O. A. Peterson in Sioux County, Nebraska. Originals in the Carnegie Museum, Pittsburgh, Pennsylvania.

Peccaries abounded, and the last of the giant pigs, the entelodonts, were present, one of them, in the Lower Pliocene, being over 6 feet tall (*Dinohyus*). The oreodonts were still common (Fig. 506) but after the Middle Pliocene declined rapidly. The first true deer appeared in the Lower Miocene and in addition there were hornless deer and antlered deer-antelopes that were slender and graceful little creatures.

Among the carnivores, the dog kinds were in great variety, some small, others as large as the largest bears. True cats appeared here for the first time, and the sabre-tooth tigers were plentiful though not large. There were also weasels, martens, otters, and racoons, but no bears are known in America before the Pleistocene.

Pliocene Mammals. — Of Pliocene mammals not much can be said because strata of this age are scarce. The continent stood high and was undergoing elevation in the western portion, with the result that the rivers carried into the sea their loads of sand and mud.

Probably the most interesting animals were the great ground-sloths and the glyptodonts (Fig. 514), because they came from South America among the migrants that traveled north over the Central American connection established in Miocene time. From the north there radiated over the same land bridge into South America in Pliocene time large sabre-tooth tigers (*Smilodon*), large cats, dogs, racoons, horses, llamas, deer, mastodons, tapirs, peccaries, etc.

Of mastodons there were several species in the Pliocene of North America; the horses, in considerable variety, were still three-toed; llamas and the tallest of giraffe-like camels continued to live; rhinoceroses with and without horns were present; sabre-tooth tigers and true cats existed, some of them as large as the lion.

Euroasiatic connection with North America is again indicated by the migration of American camels into China and India during the Pliocene. At the same time the hollow- and twisted-horned antelopes came into America.

Evolution of the Camels

Origin. — The family Camelidæ, including the llamas, guanacos, and camels, now restricted to the desert areas of central Asia and the colder parts of South America, had its origin, strange as it may appear, in the Upper Eocene of North America and a complete development there in the Tertiary. The llamas began to spread southward through the tropics into South America in the Pliocene and at the same time the camel stock radiated northward through cooler climes and across the Alaska-Siberia land bridge into Asia and Africa. Large camels were still plentiful in North America during the earlier half of the Pleistocene, but became extinct near the middle of this time.

Distinguishing Characters. — In the more recent members of the Camelidæ the legs and feet are very long and there are but two digits (even-toed = Artiodactyla) on each foot, the third and fourth, which bear hoofs. These, however, do not support any weight of the body

and are no more than nails. Beneath the feet in living camels there is a single broad pad, and in the llamas there are two separate pads of elastic tissue that bear the weight of the animal. The great single hump in the living dromedary and the pair of humps in the living Bactrian camels consist of fat. These do not impress themselves upon the skeleton and one can not therefore tell whether or not the fossil forms of the family had such humps. The long neck is always made up of seven vertebræ.

The Camelidæ are ruminants or cud-chewers of vegetable food. This is passed from the gullet into the first chamber of the stomach, then into the second, and after a time goes upward through the gullet again to the mouth, where it is remasticated; then it passes to the third and finally to the fourth or true stomach, where gastric digestion takes place.

Evolution. — Scott, from whom the following is largely taken, states that the mode of evolution shown by the camels differs in no significant regard from that seen in the horses. There was the same increase in bodily stature and in the relative lengths of limbs and feet, a diminution in the number of digits from the original five to two (3 and 4) in camels (Fig. 507), and to one (3) in horses (Fig. 508), and a similar development of the high-crowned grinding teeth from the low-crowned browsing type. The two families of camels and horses each arose in a single series. This monophyletic condition continued through the Eocene and most of the Oligocene, but in the later Oligocene and more markedly in the Lower Miocene the camels and horses branched out, each in their own fashion. In a general way, they kept quite an even pace in their advance from the more primitive to the more specialized condition.

Geologic Succession. — The camels may have had their origin in the Lower Eocene (Wasatch) in a tiny creature even smaller than the domestic cat (*Trigonolestes*), which probably had five toes on each foot. A little later (Middle Bridger), however, is found an animal (*Homacodon*) that appears to be a member of the camel family, a creature but little larger than the preceding. The head was cameline in appearance, but each foot had four functional digits (2, 3, 4, 5).

In the Upper Eocene (Uinta) occurs a camel hardly larger than a jack-rabbit (*Protylopus*, Fig. 507 *C*, *G*). The front limbs terminated in four functional digits of nearly one size, but in the hind legs there were but two functional toes, with two tiny dew-claws. In the Oligocene (White River) there was a continuous series of these animals (*Poëbrotherium*, Fig. 507 *A*, *D*, *H*), increasing in size to about that of a sheep, but of much lighter build, with small, pointed, cameline heads, relatively long necks and bodies, and long, very slender limbs and feet. The limbs were of nearly equal length, each terminating in two separate digits and nodular vestiges of two others, and deer-like hoofs. This type of foot then persisted into the Lower Miocene. In the Lower Oligocene there is indicated but

a single generalized phylum of camels and from it diverged three lines, each one of which evolved into different camel-like animals. First were given off the giraffe-camels, so called because they resembled and fed like giraffes (Fig. 507 *B*); at about the same time originated the short-lived gazelle-camels (*Stenomylus*),

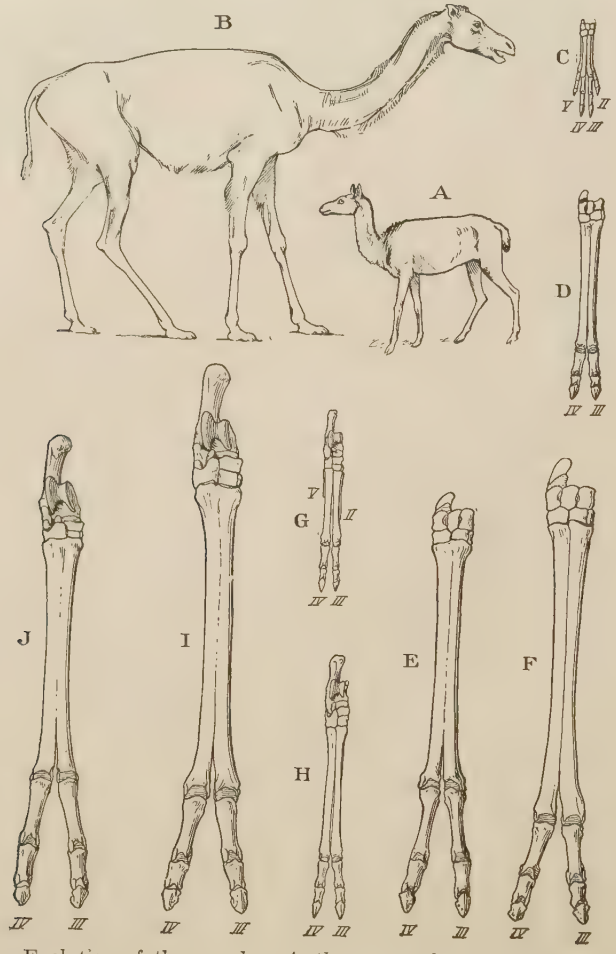


Fig. 507. — Evolution of the camels. *A*, the ancestral camel (*Poëbrotherium*). *B*, primitive giraffe-camel (*Oxydactylus*). *C-F*, right hand of a series of progressively younger camels (*Protylopus* of the Uinta, *Poëbrotherium* of the White River, *Procamelus* of the Miocene, and the living guanaco). *G-J*, right foot of the same series. *B* from Osborn's *Age of Mammals*, the rest from Scott's *History of Land Mammals*.

which were delicate in build; and finally arose the long-lived main stem which bifurcated into two phyla, the llamas and the true camels.

The giraffe-camels of the Lower Miocene were divided into two groups, the larger browsers (*Oxydactylus*, Fig. 507 *B*) and the smaller grazers (*Protomeryx*).

The feet in both groups were like those of antelope and deer. This is a most significant fact, because in both grazing and browsing camels of the Lower Miocene the stocks were already distinctly separated. Neither had yet attained to the type of foot-structure which both of them afterward independently acquired. This is a very instructive example of parallel evolution in closely related series. In the Middle Miocene the browsers (*Alticamelus*) had already developed foot-pads, had attained to great size, with extremely long necks, enabling them to feed on the higher foliage of trees, and were at the acme of their importance. They were restricted to North America and died out in the Pliocene.

The true camels arose in the Middle Miocene in a generalized stock of smaller grazing animals (*Protolabis* and *Miolabis*) that probably were without the foot-pads. In the Lower Pliocene the llamas and true camels were clearly differentiated from one another, and the feet were provided with pads. In general structure they were not unlike the living species. Although some forms were large, they all died out in North America during the later Pleistocene.

Evolution of the Horses

Origin. — The horse family (Equidæ, from *Equus caballus*, the living horse) appeared almost simultaneously in Europe and America in the "dawn horse" (*Eohippus*) early in the Eocene, but it was in North America that this group of animals passed through the greater part of their later development. In Europe the horses died out in the Eocene, and Asia was restocked from America by way of Siberia and Alaska early in Miocene time. Late in the Miocene the horses of North America spread into South America. In the American Pleistocene there were many species of *Equus*, but the immediate ancestor of our domestic horse was not among them, and the entire tribe vanished in the later part of this period. The living species originated in Europe or Asia and was introduced into this country by the Spaniards.

Distinguishing Characters. — The living horses, asses, zebras, and quaggas belong to the odd-toed hoofed mammals (Perissodactyla) and are characterized by the very long and slender feet, each composed of but a single functional toe, the third digit. The animals walk upon the very tips of the toes, the wrist being what horsemen call the "knee," and the heel, the "hock." As the third toe in each limb supports the horse, it is necessarily much larger than in animals in which the weight is distributed among several digits. There is, however, on each side of the functional digit a vestigial one, the second and fourth of the original five in the ancient ancestors (Fig. 508). The whole structure of the horse is preëminently adapted to swift running; they are admirable running machines, and every part of the skeleton has been modified and specialized to that end.

The living horses are grazers and have extremely long teeth, the

molars being excessively complex in the arrangement of the enamel ridges and the areas of dentine and cement (Fig. 505). The grazing horses continue back into the Tertiary, but before the Middle Miocene all were browsers.

Evolution. — There is no stock of mammals better known than that of the Equidæ, and they have become the classic example or "show animal" of evolution. In fact, the famous Yale University collection, assembled by Professor Marsh, did much to demonstrate the truth of Darwinism (study Fig. 508). Scott summarizes the long and marvelous development of the horse family as follows: (1) In size there was a somewhat fluctuating increase, leading by slow gradations from the diminutive horses of the Lower Eocene, about the size of a cat or fox-terrier, to the great animals of the Pleistocene, about 14 hands tall. (2) The molar teeth, originally low, cusped, and with roots, gradually changed from the browsing type to the very long, prismatic, complex, grazing teeth, and the lower jaws grew in depth to accommodate this elongation. (3) The face grew relatively longer and the eyes were progressively shifted farther back. (4) The short neck was greatly elongated and the individual vertebræ modified so as to give flexibility with no loss of strength. (5) The limbs grew relatively much longer, the bones of the fore-arm and lower leg were fused together, the one on the inner side (radius and tibia) enlarging to carry the entire weight, and the external one (ulna and fibula) becoming more or less atrophied. (6) The feet were much elongated and the median or third digit of each gradually enlarged until it carried the whole weight, at the same time modifying the shape of the hoof so as to fit it to be sole support of the body. The other toes gradually dwindled and became functionless, though often retained as splints. The first digit was first lost, then the fifth, then the second and fourth were reduced to dew-claws and finally to splints. Thus the pentadactyl horses of the Lower Eocene were transformed into the monodactyl species of the Pliocene and Pleistocene.

Geologic Succession. — The most ancient known member of the family Equidæ was the "dawn horse," which swarmed in the forests and glades of the Lower Eocene (Wasatch). They were graceful little creatures no larger than a cat or about 11 inches tall at the withers. They had on the front feet four functional digits and the vestige of another, while the hind feet had three toes and two tiny splints, the vestiges of the first and fifth digits. This evidence clearly indicates that *Eohippus* originated in ancestors with pentadactyl feet. The molars were cusped and short and of the browsing type; the neck was very short, the body long, with an arched back, the limbs and feet short, and the hind limbs much longer than the fore (Fig. 508).

The Oligocene horses were intermediate in development between those of the

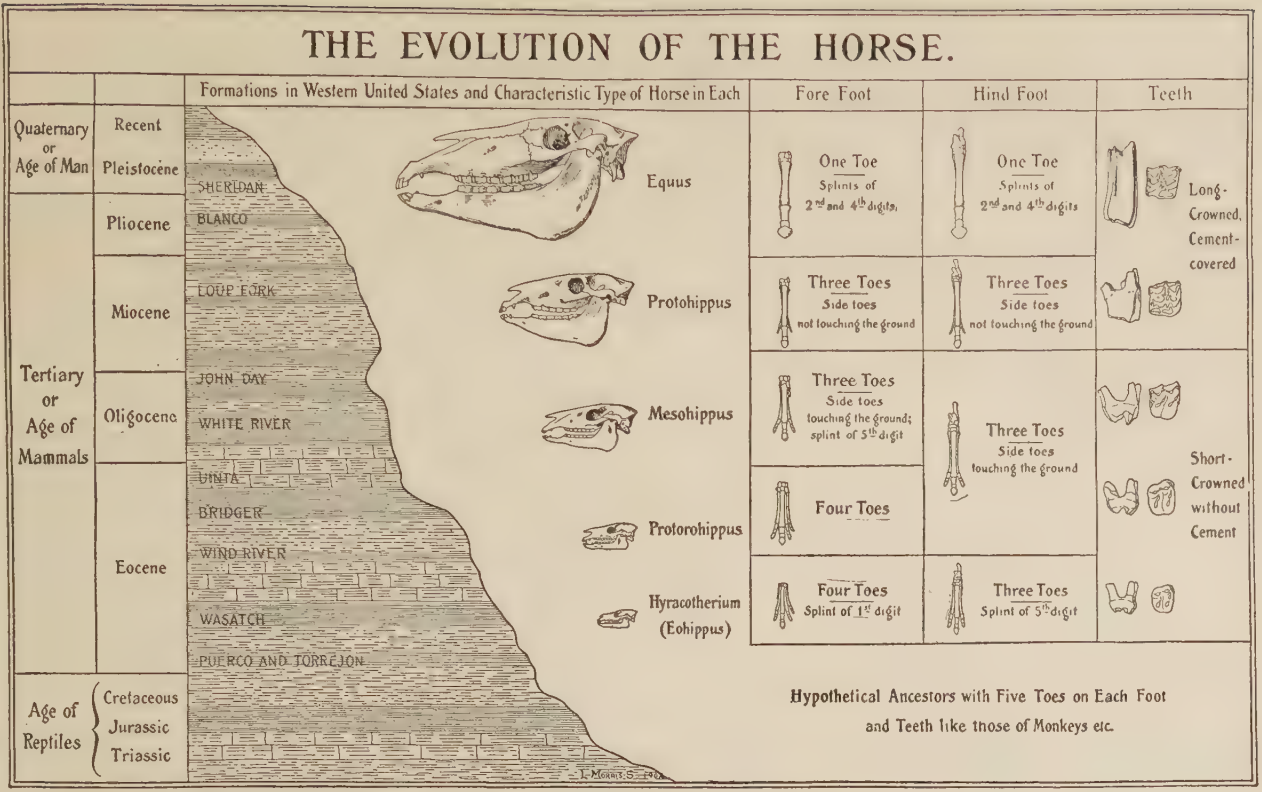


Fig. 508. — Diagram showing the evolution of the horse. After Osborn.

Eocene and Miocene. In the Lower Oligocene (White River) the largest ones were of the size of sheep (*Mesohippus*), and while the teeth were low-crowned and of the browsing type, they were changing toward those of the grazing animal. The front teeth had three functional toes, and even though the middle one was the largest, the two lateral digits touched the ground; the hind feet were also three-toed, but there were no splints present (Fig. 508).

In the Middle Miocene the three-toed horses were still mostly browsers, though some of the progressive ones were changing rapidly toward grazers. It is here that we get the intermediate forms (*Merychippus*) and note the splitting up of the horse family into several independently developing phyla. The Lower Pliocene had both progressive and conservative types of these animals. In the Middle Pliocene, among the herds of horses roaming the plains, there were three phyla of three-toed grazing horses, but the lateral digits no longer touched the ground; while they were "dew-claws," however, they were still at times of some supporting value. In the Upper Pliocene occurred the last of the three-toed browsing and grazing horses, and here lived also the first one-toed grazing member of the genus *Equus* (Fig. 508). In the earlier half of the Pleistocene there were at least ten species of the same genus, and among them horses larger than any now living.

Evolution of the Elephants

Origin. — The trunk-bearing mammals or Proboscidea had their origin early in the Tertiary of northern Africa. In the Fayum, southwest of Cairo, in late Eocene time lived the progenitor of the elephants (*Mœritherium*), an animal the size of a tapir. The head was long and narrow, with a rudimentary snout or proboscis, and the brain case was small. The most interesting feature, however, is the appearance of tusks that originated in the second incisors, the other front teeth remaining small. The incipient upper tusks were quite prominent and directed sharply downward, while those of the lower jaw were nearly procumbent, with a slight upward inclination (Fig. 509).

Evolution. — *Mœritherium* gave rise indirectly to *Palæomastodon*, an unmistakable proboscidian which persisted into the Lower Oligocene. It was about the size of a tapir, the narrow face was more drawn out than that of its ancestor, and there was a well-developed, flexible snout rather than a trunk. The tusks of the skull were longer, compressed, and more outwardly directed; those of the jaws, while larger, pointed straight forward. All of the grinding teeth (premolars $\frac{3}{2}$, molars $\frac{3}{3}$) were in place and functioned at the same time, which is not true of the later proboscidians (Fig. 509). The limbs were like those of elephants, but the brain was larger, and this tendency toward a greater cerebrum may have been the factor that permitted the proboscidians to flourish over most of the continents (Australia excepted), and to survive into the present time.

Africa and Europe were reunited at some time in the Oligocene, and across this land bridge the primitive elephants migrated into Europe.

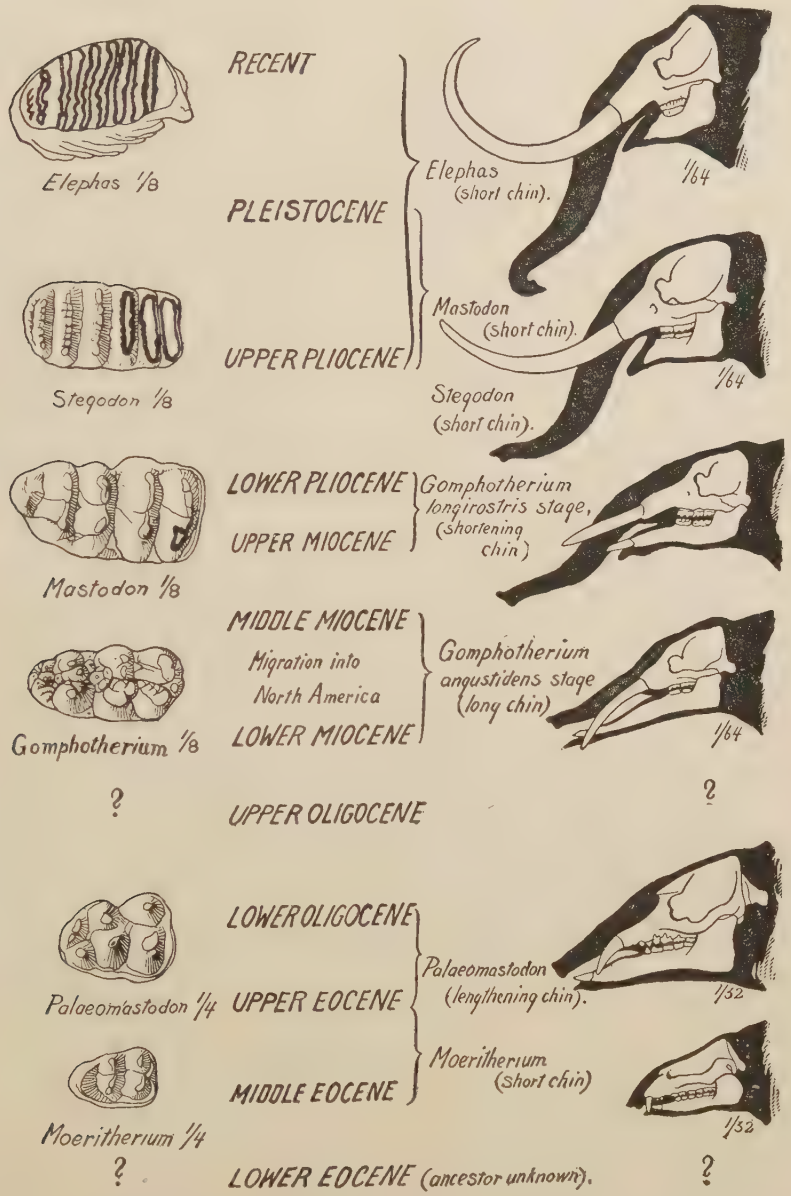


Fig. 509. — Evolution of the Proboscidea. On the right, a series of skulls with the flesh restored in silhouette. On the left, last lower molar. From Scott's *History of Land Mammals.*

They appeared suddenly in the Lower Miocene of France and by the Middle Miocene had spread into Asia and to North America. Finally, in Pliocene time, the mastodons, but not the elephants, reached South America.

It was the very long-faced, four-tusked proboscidians (*Gomphotherium*) that were so widely distributed in the Miocene and Pliocene (Fig. 509). These primitive forms gave rise in the Pliocene of India to the elephants and mastodons with two large tusks in the skull, while those of the jaws were absent or very rudimentary. In the Pleistocene of North America there were three kinds of elephants and one of mastodon (Fig. 513).

Summarizing the evolution of the Proboscidea, according to Lull: Increase in size and the development of pillar-like limbs to support the enormous weight; increase in size and complexity of the teeth and their consequent diminution in numbers and the development of the peculiar method of tooth succession; loss of the canines and of all of the incisor teeth except the second pair in the upper and lower jaws and the development of these as tusks; gradual elongation of the symphysis or union of the lower jaws to strengthen and support the lower tusks while digging, culminating in *Gomphotherium;* the apparently sudden shortening of this symphysis following the loss of the lower tusks and the compensating increase in size and the change in curvature of those of the upper jaw.

The increase in bulk and height, together with the shortening of the neck required by the increasing weight of the head with its great battery of tusks, necessitated the development of a prehensile upper lip which gradually evolved into a proboscis for food-gathering. The elongation of the lower jaw implies a similar elongation of this proboscis in order that the latter may reach beyond the tusks. The trunk did not, however, reach its greatest usefulness until the shortening jaw, removing the support from beneath, left it pendent as in the living elephant.

CHAPTER LIV

PLEISTOCENE TIME AND THE LAST GLACIAL CLIMATE

The Pleistocene or Quaternary, the final division of geologic chronology, and the culmination of the Cascadian Revolution, though brief as compared with the older divisions, was one of the critical times in the history of the earth. It was the time of the "Great Ice Age," and the record of the areas where the ice-fields prevailed consists in the main of a varied and most often a heterogeneous series of continental deposits, all of this being the Diluvium or deluge material of the older philosophers and the drift or tills of modern students of earth science. Outside of the areas of glaciation the strata are in general like other continental formations laid down under moist and warmer climates. The exposed marine record is nearly everywhere very scanty, and the molluscs are almost all (at least 90 per cent) or all still living. The life of the land was also dominantly of living forms, though here the percentage of extinct species was greater than in the seas. The term Pleistocene was therefore proposed by Lyell to bring out the fact that the life of this time was very much like that of the present.

Cold Climate of the Pleistocene. — The distinguishing physical feature of Pleistocene time was its very extensive glaciation; in fact, there appear to have been a series of glaciations, for ice-sheets covering about 8,000,000 square miles of the earth's surface existed at one time or another during this period in the temperate and colder regions of the two hemispheres (Fig. 510). This is all the more remarkable when we consider that the ice-sheets were mainly of the low lands, and that the climates for a very long time previous had been mild. All of the water of these ice-sheets had been taken from the oceans and precipitated as snow on the continents. The decrease of temperature was such that the snow-line (see page 111) was lowered about 4000 feet below its present limit (Fig. 512), and the strand-lines of the oceans in the tropical and warm temperate regions, because of the abstraction of ocean water, were depressed probably not less than 200 feet and not more than 300 feet. Finally, the loading of the lands with so much ice caused the crust to subside in the areas of the ice-sheets, while the regions immediately outside of the latter were

apparently somewhat upwarped in compensation by the displaced deep-seated material of the sinking fields. The surface of the glaciated lands was therefore more or less unsteady, warping up and down some hundreds of feet in consonance with the changes going on in the ice-sheets during Pleistocene time. In addition, broad crustal movements unrelated to the glaciation had been in progress during the Pliocene and continued at intervals in the Pleistocene. As a result of these combinations of several causes the streams and shore-lines generally show at the present time the marks of extreme youth — sharp gorges, drowned channels, barrier beaches, and elevated strand-lines.

Critical Life Conditions during the Pleistocene. — The development of such immense ice-fields upon the lands and the attendant reduction of temperature also mean the blotting out of vast areas on which no life or at least but little could exist. The Pleistocene was, therefore, a critical time in the history of the earth, especially for the plant and animal life of the glaciated lands and the shallow-water life of the northern and southern oceans. The cold waters, pouring into the oceans, sank into the depths, and the conditions there also became critical for the sparse life. In the shallow waters of the warm parts of the ocean, however, there was almost no change in the environment, and consequently there is recorded here almost nothing more than the usual evolutional faunal alterations.

Recent Time. — The Pleistocene was followed by the Recent, or present time, but how long this has been going on can not yet be stated. In a general way, we may say that the estimates vary between 20,000 and 50,000 years, with the probability that the smaller figure may be nearer the truth. As man has dominated the organic world since the beginning of the Recent, this is also known as Psychozoic time, a name given it by Le Conte. We are living in the opening events of a new era, the Psychozoic Era, but how long it is to last before another critical closing time appears, who can tell?

General Distribution of Glaciation

In the discussion of Pleistocene glaciation it should be recognized that the ice has only partly withdrawn. Greenland and Antarctica are still mantled with continental ice-sheets in contrast to their unglaciated state in earlier periods. It is the excess of glaciation beyond the present areas that is to be considered in the discussion of the wide distribution of the ice-fields of the Pleistocene.

More than half of the glaciated area during the Pleistocene was in North America, and more than half of the remainder in Europe.

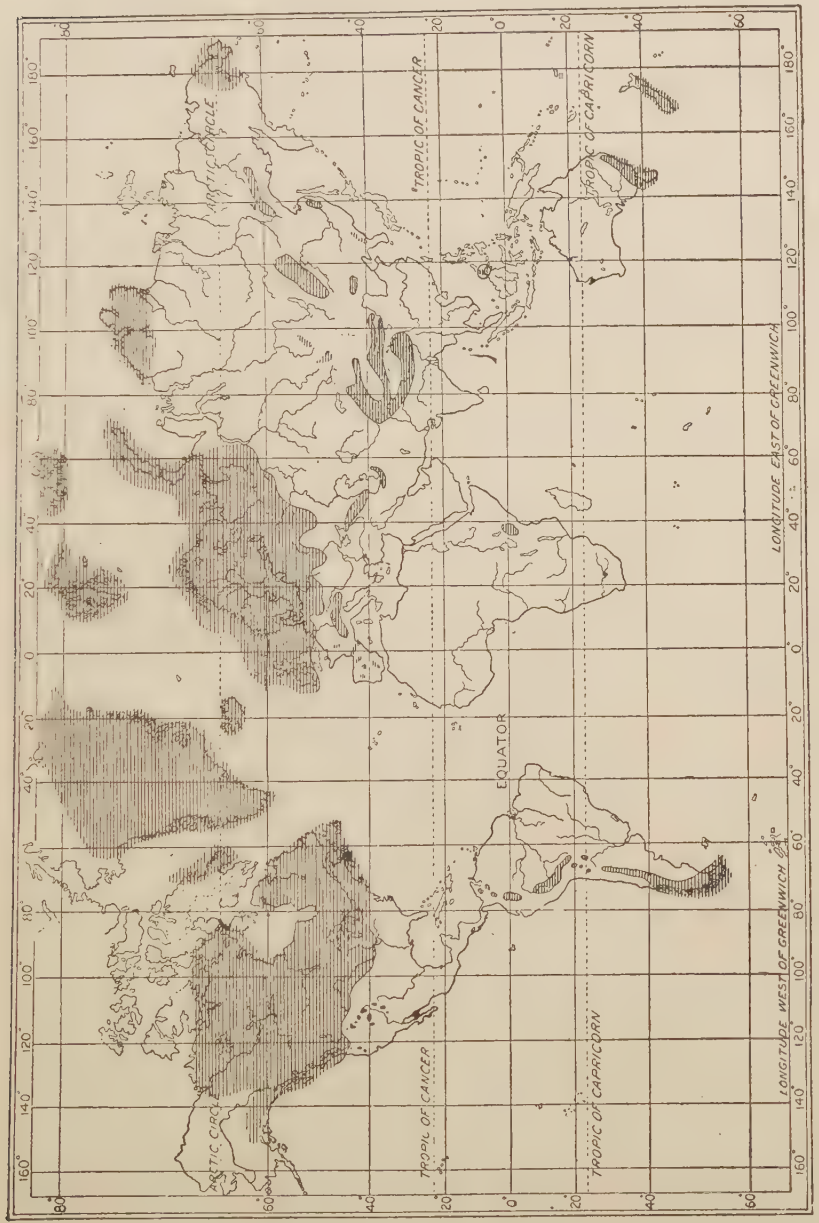


Fig. 510. — World map of Pleistocene glaciation. Carnegie Institution of Washington.

The glaciation was, therefore, notably localized, though its effects were world-wide (Fig. 510).

North America. — In North America it was mainly the north-eastern half, and the plains country rather than the mountainous region that was deeply buried under the continental glaciers (page 118). Alaska was in the main free of ice and the same appears to have been true of the Arctic archipelago. There were three great centers of ice accumulation and radiation in North America, covering together an area of about 4,000,000 square miles (Fig. 511). The

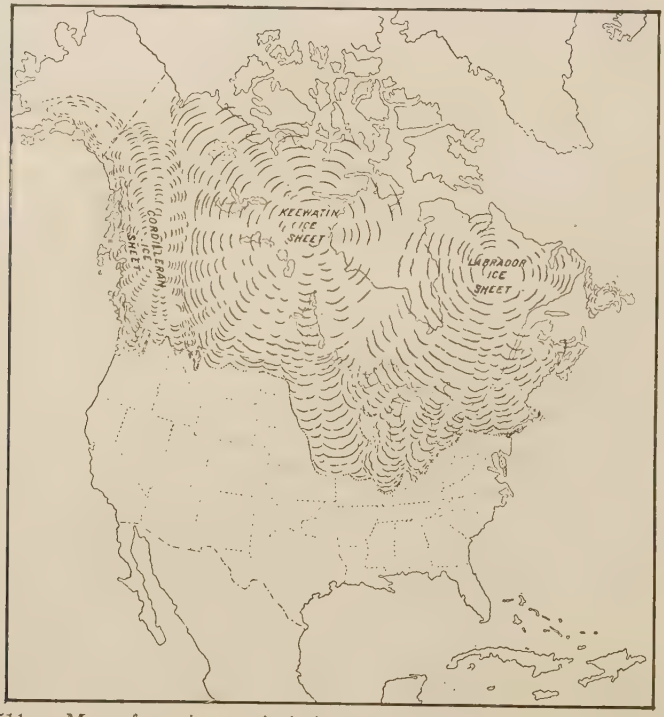


Fig. 511. — Map of maximum glaciation of North America. After Salisbury.

Keewatin ice-sheet was the most extensive, covering the great medial flat area of the continent southward into Missouri and westward into the high plains to within 800 to 1000 miles of the Rocky Mountains. The *Labradorean ice-sheet* was not much smaller, and extended from northern Labrador southwestward for 1600 miles to the Ohio River. The main flow of the ice was southward toward the region of melting, marked by greater warmth. *Newfoundland* and *Nova Scotia* appear to have had independent ice-sheets, while *Greenland* was glaciated more extensively than now but not completely across Davis Strait so

as to connect with the Labradorean mass. The *Cordilleran ice-sheet* covered all of the Cordilleran area from Alaska southward into Oregon, Idaho, and Montana. Farther south there were local alpine glaciers in the Rocky Mountains and in the Coast Range and the Sierra Nevadas of California.

Other Countries. — All *northwestern Europe*, *Iceland*, and *Spitzbergen* were deeply buried under ice-sheets, and the glaciers of the Alps descended far beyond their present limits and coalesced on the low lands in all directions. In the Himalayan region and locally in eastern Asia there were other mountains which were broadly glaciated. In the southern hemisphere, doubtless because of the absence of broad lands in high latitudes, there was comparatively little glaciation, most of it being restricted to the Andean areas. *Antarctica* is assumed to have been as deeply covered with ice then as it is now. (See Fig. 510.)

Thickness of the Ice-sheets. — How thick the Keewatin and Labradorean ice-sheets were is not known. It is widely held, however, that they must have been some thousands of feet in depth to have enabled them to flow southward with a descending grade across the higher irregularities. Le Conte places the thickness at 10,000 feet over Canada and 6000 feet over New England, where the depth is known to have been at least 4000 feet. Geologists as a rule believe that the thickness at the centers of ice dispersion could not have been less than 4000 feet, and that it may have exceeded this average depth.

Alternating Cold and Warm Stages

It is a well-known fact that in most areas of past glaciation there occur, between sheets of drift, beds of peat and clays with fossil leaves and wood, and sands with bones of many kinds of large mammals. These fossils show clearly alternating groups of plants and animals living in different climates; one set is of northern origin and of cold habitat, while the following one is from the south and of mild climes. The cold climate assemblages have among other forms reindeer, caribou, musk-oxen, moose, woolly mammoths (Fig. 513 *C*), and walrus, while those of the warm climates have lions, sabre-tooth tigers, peccaries, tapirs, camels, llamas, many horses, hippopotamuses, great sloths (Fig. 514), the Columbian and Imperial elephants (Fig. 513 *B*, *D*), and the manatee or sea-cows. It is the succession of these fossils in the Pleistocene strata that has led to the discerning of alternating warm and cold climates. These marked alterations led to very extensive migrations of mammals from one part of the continent to another, as the conditions of temperature and moisture changed. During the warm interglacial times, southern species

spread far to the north, as when mastodon ranged into Alaska (Fig. 513 *A*) and the sea-cow spread north to New Jersey. Increasing cold and the spread of glaciation brought about a reverse migration and drove northern and even Arctic forms far to the south. Musk-oxen then spread into Utah and as far south as Oklahoma, the northern or woolly mammoth (Fig. 513 *C*) lived south of the Ohio and Potomac rivers, and the walrus had its home along the strands of New Jersey.

It has come to be generally held, therefore, that during the Pleistocene the temperature varied more than once between cold and warmer climates. During the cold times there was increase in the extent and thickness of the continental ice-sheets, and during the warmer interglacial stages the ice was melted away to a greater or less

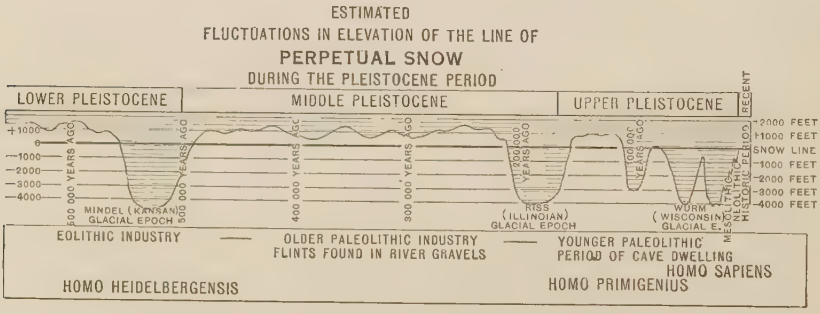


Fig. 512. — Diagram illustrating the probable variations of the snow-line during most of the Pleistocene and Recent, on the basis of a conservative time estimate stated in years. Drawn to scale. The succession of human events is also indicated. Prepared by Joseph Barrell.

degree. However, as to the number of these alternations there is as yet no unanimity among geologists, because of the great difficulties in correlating the separated areas of glacial material, all of which are so much alike. Some geologists recognize three, and others as many as six glacial stages, with from two to five interglacial warmer times (Fig. 512).

It is also now widely accepted that the interglacial times were markedly variable in duration and that all of them were not only warmer than the present, but that they lasted longer, and sometimes much longer, than the glacial stages. In Europe one of the interglacial times was so warm that the lion and the hippopotamus lived in England, and in North America the pawpaw bush spread north at least as far as Toronto while to-day it is not known to live much above the Ohio River.

Chamberlin and Salisbury divide Pleistocene time as in the first column of the following table, and the statements concerning the mammals in the second column are after O. P. Hay.

Divisions of Pleistocene time in North America

Post-glacial or present time	Vanishing of ice-sheets. Champlain marine invasion. Lowering of water-level of Great Lakes. Gradual amelioration of climate. Gradual extinction of elephants, mastodons, *Megalonyx*, musk-oxen, etc.
Fifth or Wisconsin glacial stage Würm stage in Europe	Spread of ice-sheets and drift. Fauna and flora driven south.
Fourth or Peorian interglacial stage	Record not well determined. Formation of peat beds and soils. Wide distribution of loess.
Fourth or Iowan glacial stage	Spread of ice-sheets and drift. Record not well determined.
Third or Sangamon interglacial stage	Accumulation of peats, soils, and loess. Horses, elephants, mastodons, bison, peccaries, and tapirs probably present.
Third or Illinoian glacial stage Riss stage in Europe	Spread of ice-sheets and drift. Deposition of loess. Apparently 60 per cent of present land fauna then living. Mastodons, mammoths, horses, tapirs, bison, deer, and sabre-tooth tigers.
Second or Yarmouth interglacial stage	Formation of peats, soils, and bluish loess. Animals about as in Illinoian stage.
Second or Kansan glacial stage Mindel stage in Europe	Spread of ice-sheets and drift. Extinction of certain camels and horses.
First or Aftonian interglacial stage	Great abundance of mylodons, megatheres, *Megalonyx*, mastodons, elephants (3 species), horses (6 species), camels (4 species), sabre-tooth tigers, bears, etc. A warm temperate fauna.
First or Sub-Aftonian glacial stage	Spread of ice-sheets and drift. Includes Pre-Kansan, Nebraskan, and Albertan drifts.
Pliocene	

Effects of the Glacial Climate

Historical. — During the greater part of the past century, geologists holding strictly to supposed implications of the Laplacian theory of earth origin believed that the earth had been gradually cooling and that it became cold for the first time in the Pleistocene. When, therefore, the first announcements were made, nearly fifty years ago, that a cold climate had been present in the Permian (see

page 758) most of our colleagues of those days could not accept what is now undoubted evidence. The controversy over the origin of the Pleistocene glacial deposits, however, not only made it possible to accept the evidence of the drifts and tills as the result of ice work, but paved the way for the evidence of other and older geologic climates. We now know that such occurred much farther back in the history of the earth, one toward the close of, and another earlier in, Proterozoic time (pages 570 and 560). There is evidence of yet other cool periods, and it is probable that we shall learn that the earth has undergone more than four glacial climates (see Fig. 520).

Our knowledge of glaciation had its origin in the Alps, the land of magnificent scenery and marvelous glaciers, through the work of Andreas Scheuzer early in the eighteenth century. This was at first only a study of the interesting local glaciers, but out of it gradually came about, especially through the studies of Louis Agassiz between 1836 and 1847, the application of conditions observed in the Alps to the very widely distributed glacial deposits elsewhere. (The characters of glaciers are described on pages 111 to 119.) The engineer Venetz in 1821 pointed out that the Alpine glaciers had once been of far greater size, and that glaciation had been on a scale of enormous magnitude in some former period. By degrees the older conception that the erratics and tills were the result of marine floodings and floating icebergs gave way, in the third quarter of the last century, to the theory of colder climates and glaciers of continental extent. (For a detailed description of glacial deposits see pages 134 to 140.)

Changes in Drainage due to Ice-sheets. — The geologic work done by glaciers in general is described on pages 128 to 134. Erosion by the continental ice-sheets was unequal and the deposition of the drift materials was especially irregular in distribution. From this it follows that the drainage system of the land was deranged and considerably modified. River valleys were locally filled by the drift to depths ranging up to 400 feet, or partially covered over by the ice, forcing the drainage around its front, as was the case in the middle course of the Ohio River. In fact, the drainage of the glaciated areas was in certain regions revolutionized. Chamberlin and Salisbury state that there were few streams of great length in the areas covered by the ice that were not turned from their old courses for greater or less distances by the ice or the drift. The Ohio and the Missouri — the master streams of the United States marginal to the glaciated area — were built up from previous systems, and a host of their tributaries within the glaciated area suffered marked changes.

Origin of the Great Lakes. — All ice-sheets push out lobes along the preëxisting valleys, and those of the Great Ice Age, especially during the Wisconsin stage, were no exception to this rule. Accordingly, the Keewatin ice-sheet, when it finally melted and re-

treated across the area of the Great Lakes, had lobes that extended along the ancient valleys (see Fig. 104), scouring them deeper, and leaving in front, as they receded, small lakes that grew to ever greater proportions and were variable in outline. The first to appear were Lake Chicago, the beginning of Lake Michigan; Lake Saginaw, a part of the future Lake Huron; and Lake Whittlesey, which was of considerably larger extent than its descendant, Lake Erie. At this time, certain of the present small rivers were large, as the St. Croix, Wisconsin, Rock, and Illinois, draining the vast melting waters of the Keewatin ice-field into the Mississippi River. In central New York the "finger lakes" were considerably larger than they are now and their waters for a long time drained into the Susquehanna River, and later through the Mohawk and Hudson rivers. Finally, when the ice had retreated well into Canada, all the Great Lakes were connected far more widely than they are now and drained out eastward through the Ottawa and St. Lawrence into the Champlain marine inundation, to be explained later.

Lake Agassiz. — As the ice retreated from Minnesota, the Dakotas, and Manitoba, it left a shallow basin in which another great lake came into existence. Lake Agassiz, as it is called, was once five times as large as Lake Superior, but when the ice-sheet which blocked its northern edge finally melted away, the waters of the lake were drained off, leaving only much smaller lakes, such as Winnipeg, in the deepest parts of its basin. Its existence has been determined from the many raised terraces and sandy beaches made by its waves, and by the broad, flat bottom built of fine silts which were deposited in the lake. This alluvial plain is now one of the richest wheat-growing districts in the world. For other large lakes of Pleistocene time, such as Lakes Lahontan of Nevada and Bonneville of Utah, see pages 79 and 80.

Champlain Marine Invasion. — When the ice-sheets had finally retreated into Canada and across the St. Lawrence valley, the Atlantic Ocean found the glaciated lands depressed, and not only entered the depression but filled it at least 600 feet deeper than now. This was, therefore, a time of inland or epeiric seas, and it is probable that at this time also appeared Hudson Bay. In other words, a great part of eastern North America sunk under the enormous load of the ice-sheet and when the latter vanished the Atlantic was permitted to flood deeply Hudson Bay, the St. Lawrence and Ottawa valleys, all of Lake Ontario and Lake Champlain, and southward to the east of Lake George. Marine shells and the bones of whales and seals are found about Lake Champlain at elevations of up to 440 feet above

the present level of the water, and at 520 feet near Montreal (see page 73 under relic lakes and page 493).

Oscillations of Strand-lines. — At no time in the Pleistocene earlier than the Champlain invasion is it known that either the Atlantic or Pacific oceans to any great extent invaded the continent. In other words, North America stood higher above the strand-line than was the case at any time during the Tertiary. However, it is known that the strand-line was not constant, but that it oscillated up and down within some hundreds of feet. These alternations were probably due to the warping up and down of the continent, as explained on an earlier page.

Marked Changes in Europe. — During the Pleistocene Great Britain remained in connection with northern France (region between Calais and Boulogne) and the then eroding outer valleys of the Seine and Somme are now flooded by the English Channel. On the other hand, the Thames and the great Pleistocene Rhine flowed out much farther north, and their outer plains and valleys are now occupied by the North Sea. The shallow Baltic Sea, like Hudson Bay, also originated in Pleistocene time. In southern Europe great down-sinking of certain basins has been in progress, and the Black Sea of southeastern Europe is of very recent origin. Sicily and Malta were united to Africa and the connecting land was faulted into the depths of the Mediterranean at about the Middle Pleistocene.

Duration of the Glacial Period.— There is as yet no definite method of determining the length of time that the Pleistocene endured. The estimates are matters of judgment and therefore little more than guesses. It is assumed that the Pleistocene came to a close about 20,000 to 50,000 years ago. All of Pleistocene time has been estimated at not less than 400,000 years, and some geologists suggest that it may have endured even longer than 1,400,000 years. The truth probably lies somewhere between these estimates, with the probability toward the smaller figure (see Fig. 512).

Record of Lands to the South of the Ice-sheets

The glaciated area has a topographic expression all its own, for here we find the drift in its many forms, erratic stones, large and small, and a striated and scoured ground. Soils are mostly yellowish and thin or absent, and everywhere occur lakes of varying sizes occupying the depressions. In front of the ice-sheets occur the deep old soils that are usually of a reddish color, there is no drift, erratics or striated ground, the lakes and ponds are comparatively few and due to other causes. The streams are flowing in their old courses, but at lower levels.

The stratigraphic record of the warmer areas of Pleistocene time is scattering, varied, and fragmentary, and it is therefore difficult to

determine the chronologic sequence. There are wind deposits of sand and dust along the rivers and the shores of lakes, and in various arid areas occur accumulations of dust; elsewhere there are sediments of rivers and lakes and the deposits made by springs, asphalt pools and fillings of caves and sink-holes often abounding in bones, peats and marls of marshes and ponds, lavas and ashes in the areas to the west of the Rocky Mountains, and finally the fresh-water, estuarine, and marine accumulations along the borders of the continent. All of these deposits are apt to be thin and localized.

Causes of Glacial Climate

As yet there is no accepted explanation of why the earth from time to time undergoes glacial climates, but it is becoming clearer that they are due rather to a combination of causes than to a single cause. Probably the greatest single factor is high altitude of the continents, with great chains of new mountains (the hypsometric causes) which disturb the general direction and constitution of the air currents (the atmospheric causes) and the ocean currents as well.

Hypothesis of Polar Wandering. — It has often been suggested that the axis of the earth has shifted and that the north pole in Pleistocene time was 15° or 20° south of its present position. To explain the equatorial glaciation of Permian time some writers have shifted the north pole to the region of Mexico, and the south pole to the Indian Ocean; even if this were possible, however, the distribution of the ice-fields did not center about these imaginary poles. As the earth is essentially as rigid as steel, the dynamic conditions in such a mass would not permit of such changes without leaving a record of them in the structure of the earth-shell. There are no such records discernible. Moreover, it was long ago demonstrated mathematically by G. H. Darwin that migrations of the axis of the earth sufficiently extensive to be of geological importance have not occurred. "It would appear," says Barrell, "that the assumption of polar wandering as a cause of climatic change and organic migration is as gratuitous as an assumption of a changing earth orbit in defiance of the laws of celestial mechanics."

Effects of Continental Emergence. — Of the four known glacial climates of geologic history, at least three (early Proterozoic, Permian, Pleistocene) occurred during or directly after times of intensive mountain making, while the fourth (late Proterozoic) apparently also followed a time of elevation. The Laramide Revolution at the close of the Mesozoic, on the other hand, was not accompanied by a glacial climate, but only by a slightly cooler one. The cooled Lias time (page 851) also followed a mountain-making period. We therefore see that the known cooled or cold climates occurred during or immediately followed periods of marked mountain making.

Again, the three marked glacial climates of late Proterozoic, Per-

mian, and Pleistocene times and the cooled climates of the Lias and Cretaceous all fall in with times when the continents were more or less highly emergent. There were no cold climates when the continents were flooded by the oceans, and it may be added that the periods of wide-spread limestone making preceded and followed, but did not accompany, the reduced climates (see Fig. 520).

Effect of Volcanic Ash in Atmosphere. — Humphreys has shown that volcanic dust, shot very high above the cloud region of the earth's atmosphere, where it may continue to float for months, does appreciably reduce the temperature at the surface of the globe. The greatest amount of dust in the atmosphere should, therefore, coincide with the times when the volcanoes are most active, or when mountains are being elevated. An analysis of the climates during these times shows that while they may have been cooled, the dust in the higher atmosphere of the earth does not appear to have been a primary factor in bringing on glacial periods. On the other hand, it can not be denied that such periodically formed blankets against the sun's radiation may have been a contributory cause in cooling climates during some of the periods when the continents were highly emergent.

Effects of Oceanic Spreading. — The life of the seas of the past indicates vast stretches of time of mild to warm and equable temperatures, with but slight zonal differences between the equator and the poles. These were punctuated by short but decisive periods of cooled waters and great mortality, followed by quick evolution and the rise of new stocks. On the land the story of the climatic changes is different, but in general the equability of the temperature simulated that of the oceanic areas. The lands were, however, periodically inundated by warm waters, causing insular climates that were milder and moister. With the vanishing of the floods, somewhat cooler and certainly drier climates were produced. (See Figs. 520 and 521.)

When to these factors is added the effect upon the climate of the periodic rising of mountain chains, it is apparent that the lands must have had constantly varying climates. In general, the temperature fluctuations seem to have been slight, but geographically the climates varied between mild to warm pluvial and mild to cool arid. Finally, it must not be forgotten that when the lands were highly emergent, the formerly isolated lands were connected by land bridges that more or less altered the oceanic water circulation and therefore the local temperature.

Effect of Carbon Dioxide in Atmosphere. — A great deal has been written about the supply and consumption of the carbonic acid of the air as the primary cause for the storage of warmth by the atmospheric

blanket. A greater supply of carbon dioxide is said to cause increase of temperature, and a marked subtraction of it to bring on a glacial climate (see pages 84 and 457). This aspect of the climatic problem is altogether too large and important to be entered upon here. It is permissible to state, however, that the glacial climates are irregular in their geologic appearance, are variable latitudinally, as is seen in the geographic distribution of the tillites between the poles and the equatorial region, and finally that they appear in geologic time as if suddenly introduced. These differences do not seem to be conditioned in the main by a greater or smaller amount of carbon dioxide in the atmosphere, for if this gas is so strong a controlling factor, it would seem that at least the glacial climates should not be of such quick development. On the other hand, an enormous amount of carbon dioxide was consumed in the vast limestones and coals of the Cretaceous, with no glacial climate as a result; though it must be admitted that the great limestone and vaster coal accumulations of the Pennsylvanian were followed by the Permian glaciation. Again, it may be stated that the Pleistocene cold period was preceded in the Miocene and Pliocene by far smaller areas of known accumulations of limestone and coal than during either the Pennsylvanian or Cretaceous, and yet a severe glacial climate followed.

Effect of Variation in Solar Energy. — As all of the appreciable heat of the atmosphere is derived from the sun, it is necessary to examine this source to see if the quantity varies. It is now well known through the work of Langley and Abbott that the sun is a slightly variable star and that the output of radiation is variable within limits of from 5 to 10 per cent in quantity and in irregular periods of from five to ten days. Moreover, Huntington states that five authorities on glaciation have concluded that if the mean temperature of the earth were to fall 9° or 11° F. and were to remain thus low for a sufficient length of time, meteorological conditions would be so altered that a large part of North America would be covered with ice down to about the fortieth degree of latitude, and Europe would suffer a corresponding glaciation. Of course there is no direct evidence to show that the intensity of solar radiations has varied so greatly in past times. That it does vary in a minor degree, however, has been shown. This being so, Huntington postulates that at certain times the sun may have been stimulated to unusual activity, just as it is to-day when we have periods of unusually numerous sun-spots, but to a greater degree. During the times of great but short stimulation, the sun's atmosphere would also be laden with much dust, shutting in the solar heat and cooling the thermal blanket of the

earth to the extent of bringing on a glacial climate. As the solar atmosphere became clearer and more and more of its heat radiated into space, the earth would become warmer, giving rise to a long interglacial stage of usual warmth or aridity. Finally it should be added that as cold climates appear during or shortly after excessive mountain making on the earth, crustal unrest and reduced climates occur simultaneously with the hypothetical stimulations of the sun. (For further detail concerning this theory see Huntington, *The Climatic Factor.*)

Conclusions. — Briefly, then, we may conclude that the markedly varying climates of the past seem to have been due primarily to periodic changes in the sun and in the topographic form of the earth's surface, plus variations in the amount of heat stored by the oceans. The transformed face of the earth altered the configuration of the continents and oceans, the air currents (moist or dry), the oceanic currents (warm, mild, or cool), and the volcanic ash content of the atmosphere. The causation for the warmer interglacial climates may lie in the oscillations of solar energy.

Life of the Pleistocene

The most interesting life of the Pleistocene is naturally the mammalian, and even though it is as a rule very fragmentary, it is so widely scattered as to give a fair idea of its extent. In fact, as Scott says, with all its gaps, the record is impressive. The human history will be presented in the next chapter.

The most striking of the Pleistocene mammals in North America were the three species of elephants and the one of mastodon. The last named, *Mammut americanum*, migrated from Siberia into Alaska, and ranged over nearly all of the United States and southern Canada (Fig. 513 *A*). It was most abundant in the forested regions and rarer in the plains country, and persisted so long that the animal may have been hunted to extermination by the red men.

Of the elephants, the most interesting and widely distributed was the Siberian woolly mammoth (*Elephas primigenius*), an animal of the cold climate, standing about 9 feet tall at the shoulders, and coming to North America by way of Alaska (Fig. 513 *C*). It ranged from the far north through British Columbia into the United States and across to the Atlantic Coast. The mammoth also migrated from Asia into Europe and was there hunted by Pleistocene man (see Fig. 519). It died out in North America late in Pleistocene time.

Closely related to the above form was the Columbian elephant (*Elephas columbi*), of taller stature, being 11 feet at the shoulders

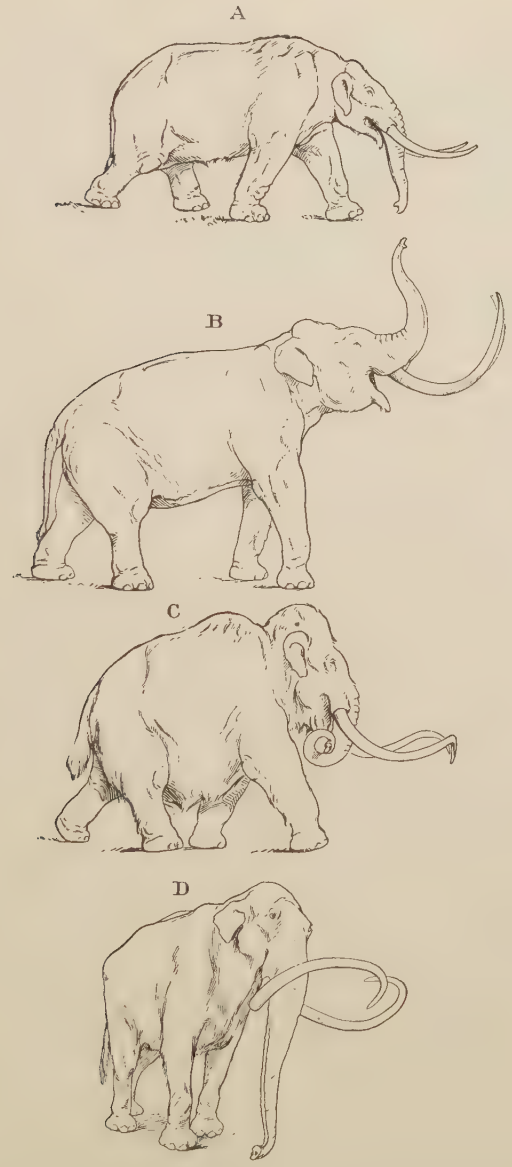


Fig. 513. — Restorations of the American Pleistocene proboscidians. *A*, American mastodon (*Mammut americanum*). *B*, Imperial mammoth (*Elephas imperator*). *C*, woolly mammoth (*E. primigenius*). After Osborn. *D*, Columbian mammoth (*E. columbi*). From Scott's *History of Land Mammals*.

(Fig. 513 *D*). It lived during the earlier half of Pleistocene time in the warmer portions of North America, roaming over the whole United States and the high plains of Mexico. The third species was the huge Imperial elephant (*Elephas imperator*), said to attain to 13 feet and 6 inches in height (Fig. 513 *B*). It was probably a plains animal that survived from Pliocene times and died out in the Middle Pleistocene. Its range was western America from Nebraska to Mexico City.

The horses were exceedingly numerous in the earlier Pleistocene, and roamed, apparently in great herds, all over Mexico and the United States and even into Alaska. There were at least ten species of *Equus*, one no larger than the smallest pony, others larger than the heaviest modern draft-horses. They were descendants of American Pliocene horses and all died out during the Pleistocene.

Of peccaries there was an abundance, and there were also camels and llamas. During the times of glaciation the caribou ranged south into Pennsylvania and musk-oxen into Utah and Oklahoma. The modern moose was present in the western half of the continent, but the stag-moose (*Cervalces scotti*) was a late arrival during the last ice invasion. Other ruminants related to the musk-ox occurred earlier in the period, and of bison there were at least seven kinds, ranging from Florida to Alaska, one species (*Bison latifrons*) with a horn spread of 6 feet.

Among the carnivores, the most formidable was the great sabre-tooth tiger (*Smilodon*), which lived over the greater part of the United States. Of rodents the most interesting was the late Pleistocene giant beaver (*Castoroides ohioensis*), as large as a black bear.

The ground-sloths were represented by a large and widely spread form, *Megalonyx*, first discovered and named by President Thomas Jefferson. The giant southern form, *Megatherium* (Fig. 514), had a body as large as that of an elephant, though shorter in limb, while the oldest and smallest of the sloths was *Mylodon*.

Fig. 514. — Giant sloth (*Megatherium*) and two kinds of glyptodonts (*Glyptodon* above, *Dædicurus* below), from the Pleistocene (Pampean) of Argentina. After J. Smit, from Knipe's *Nebula to Man*.

CHAPTER LV

MAN'S PLACE IN NATURE

The title of this chapter is the same as that of one of Huxley's famous books, in which he states: "The question of questions for mankind — the problem which underlies all others, and is more deeply interesting than any other — is the ascertainment of the place which Man occupies in nature and of his relations to the universe of things."

Man Compared with Animals.* — Man seems to us so very different from all the animals that we can not believe him to be related to them at all, and prefer to regard him as standing isolated and alone, something quite apart from all organisms. When, however, we begin to study his body and compare it, organ by organ, with that of other animals, we see that his isolation disappears, and that it is the thick veil of civilization in which he has so completely hidden himself that misleads us regarding his true position in the animal kingdom.

Stature and Posture. — The mean stature of present-day Europeans is 5 feet 6 inches, and we shall see later on that the oldest fossil men vary between this size and 5 feet 4 inches. Men of 6 feet in height did not appear until toward the close of the Glacial Period (Pleistocene) in the Aurignacian race of France. We are, therefore, not descended from a race of giants, but rather are we tending toward a taller stature.

The erect posture of man is also of ancient origin, for it is fully developed in the oldest fossil men, and probably had its beginning in the gibbons of Pliocene time. It is, however, not so much in his posture that man differs from the large anthropoids as in his manner of progression. He is adapted to living on the ground, "an adaptation which allowed him to escape beyond the limits of forests and occupy the whole world." It is, therefore, in the construction of the legs and in the setting of the entire foot upon the ground (plantigrady) that man varies much from the greater apes, and as the human leg and foot are already developed in the oldest known fossil man, it is

* Most of the information in the first half of this chapter has been taken from Keith's *Man, a History of the Human Body.*

clear that this evolution also took place prior to the Pleistocene. It was during this earlier evolution of man that the great toe, set like a thumb and used as a grasping organ, was changed into the non-grasping toe of living man. The human type of leg and foot was, then, developed long before the human brain came to be as we see it now, for in the oldest fossil ape-man (*Pithecanthropus*) the brain is little more than half the size of that in living man. The large brain of man appears to be his latest acquisition; his foot, leg, and plantigrade gait are older, his size of body older still, and his erect posture quite an ancient character.

Comparisons between Man and the Other Primates. — "The skeleton of the gorilla is not at all human in appearance, the great crests on the skull, the massive jaws and face, the long stout arms, the short lower limbs with a thumb-like great toe, seem to assure us that even the most man-like of apes is a long way off from man himself. Yet when we look more closely we see that every bone of man's body is present in the gorilla, they occupy exactly the same place in the skeleton; each bone shows the same leading features; the differences relate merely to proportion, size, and detail. When we look at the skull of the young gorilla, before the massive, brute-like crests have appeared, the human resemblance is more marked. In the skulls of the adult chimpanzee, these cranial ridges, which are developed to give attachment to the great muscles of mastication, are much smaller than in the gorilla. In the orang they are intermediate in size."

Between the higher apes just mentioned, which Huxley refers to as "blurred copies" of man, and the smaller and lower apes, the gibbons, there is another break in the evolutionary steps quite as marked as the one between man and the great anthropoids. The head and body are much smaller, there are the same bones set together in the same order, but the proportions are different. The gibbons are of early geologic origin and have clung to the ancestral form more closely than any of the other apes. Between the gibbons and the monkeys there is a wider gulf than any we have so far seen, yet we can not well say the one is higher than the other. In certain features we see that the gibbons are related to the Old World monkeys, in others to those of the New World; we believe that there must be extinct ancestral gibbons which, did we know them, would show us that these three forms of primates have all arisen from a common stock at a long past period of the world's history. Among the American monkeys we find quite small and low forms, such as the marmoset, which take us a little way toward the lemurs. "If at first

we had seen the skeleton of man placed side by side with that of the tiny marmoset we would have denied that there could be any possibility of a common origin for these two, but when we pass from the one to the other through a series which, while showing many breaks, leads us step by step from the one to the other, we begin to see that the miracle of man's primate origin is not so impossible as it appears at first."

Geologic Rise of Primates. — The oldest lemurs appear in the American Eocene (Wasatch) in a small form very much like the tarsier living in Madagascar. Diminutive monkeys appear a little later (Bridger), but before the close of the Eocene all primates seem to have become extinct in North America. In the later Oligocene of Egypt appears the oldest ape (*Propliopithecus*), apparently the progenitor of all later anthropoids. This was a small animal which spread in early Miocene time into Europe and there gave rise to the larger apes of the western part of that continent (*Pliopithecus* into *Dryopithecus*). It is, then, since Middle Miocene time that we may expect the rise of the human stock. The great-bodied primates of about this time probably divided into two independently evolving stocks, the one retaining the ancestral arboreal habitat, the other taking more and more to the ground. The former line of evolution gave rise to the gorilla and chimpanzee of Africa and the orang of Borneo and Sumatra, while the terrestrial stock developed into the ancestry of man. Living man is known as *Homo sapiens* (reasoning man) and in his varied geographical races is distributed over the entire earth. As we go back into the Pleistocene we meet with other human species, more and more primitive, and finally with the ape-man (*Pithecanthropus*) of Java.

Brain in Primates. — The brain of the higher vertebrates consists of two main parts, a lower and hinder division known as the cerebellum, and an upper part, the cerebrum, that is again divided into right and left hemispheres. In the mammals previous to the Oligocene the lower brain is the larger, but beginning with this time the upper brain, where reason and memory are located, increases rapidly in size in nearly all stocks and finally is considerably greater than and almost covers over the entire cerebellum.

In man the size of the brain depends to a certain extent upon the bulk of the body; tall men on the average have larger brains than small men. It therefore does not hold true that bulkier men with larger brains are more able than smaller ones with less weighty brains, though the fact remains that many of the world's most famous men had large heads and big brains. The brain of Bismarck and Cuvier

each weighed about 66 ounces, that of the Russian novelist Turgenieff nearly 75 ounces, while that of Gambetta, the French statesman, weighed about 42 ounces, and that of Leibnitz, a great German philosopher and mathematician, less than 45 ounces. In adult men the weight of the brain varies between 65 and 34 ounces (average 49), and in women, due to their smaller size, it is between 56 and 31 ounces (average 44) or about 12 per cent lighter than in man. When the brain is contrasted with the entire weight of the body it is about as 1 to 45.

In the smallest gorilla the brain weighs 15 ounces and in the largest 20 ounces, while the weight of the entire body at maturity varies between 200 and 418 pounds, giving a ratio of about 1 to 213. At birth the human brain weighs between 10 and 11 ounces, or about one fifth its size at maturity. By the end of the second year the human brain has attained two thirds of its adult size, and has then reached the same relative degree of development that the anthropoid has at birth. Maximum size of the brain in man is reached at about the twentieth year, and it then slowly loses weight into old age, when decrease is more rapid. "Man's prime is not a period," says Karl Pearson, "it is merely a point of time."

Embryology of Man. — All animals, however simple or complex in construction, begin in a single cell with a nucleus, and the human species begins in the same way. Thus all the higher organisms begin in comparative simplicity and develop through growth into greater complexity. The human ovum or egg, considered as a cell, is large, but actually is so small that about 125 of them when laid side by side have a length of one inch only; while the male or sperm cell that enters the ovum and starts its development is vastly smaller. Therefore, the tiny microcosm of living female and male matter has within itself the potentialities of the future man or woman, and the individual during its development and mature existence reveals not only the characters of its direct human ancestors but something of its animal line of succession as well. It is during the first three months of fœtal development that all of the great changes or transformations take place and that all parts of the body are formed. It is in fact during this early development that the human fœtus strikingly resembles that of the lower animals. The remaining six months of gestation are those of growth and maturation.

The fertilized human ovum in its development divides into two cells, these again divide, and this division of cells continues, the cells arranging themselves in a definite manner into tissues and organs. We can not follow here all the early transformations, and need only state that at about the third week of growth the body cavity begins to appear, that is, the cavities which enclose the organs of the thorax and abdomen. The fœtus is then in the cœlomate or vermian stage, that is, it now has a true body cavity and is therefore higher in construction than the cœlenterate animals (see page 643). Already in the second week the worm-like embryo begins to have a segmented body and in the following week appear four grooves on the neck of the fœtus. These grooves represent the gill slits of fishes, and the heart then also has the construction seen in fishes, that is, is two-cham-

bered. No functional gills are actually developed, however, but the structure of these vestigial gills is a clear hint that the mammalian and human lines had ancestors with this type of breathing organ, that is, among the fishes and amphibians. By the sixth week all outward appearance of the gill slits is gone; the fœtus has passed from the gilled to the lunged stage, and the fish-like heart with its two chambers has changed into the three-chambered heart seen in the amphibia, and then into the four-chambered one of mammals. The heart begins to beat in the gilled stage, but the lungs do not come into use until birth. Before then the placenta serves the purpose of respiration.

Conclusions. — "Identical in the physical processes by which he originates — identical in the early stages of his formation — identical in the mode of his nutrition before and after birth, with the animals which lie immediately below him in the scale — Man, if his adult and perfect structure be compared with theirs, exhibits, as might be expected, a marvellous likeness of organization."

"Whatever system of organs be studied, the comparison of their modifications in the ape series leads to one and the same result — that the structural differences which separate Man from the Gorilla and the Chimpanzee are not so great as those which separate the Gorilla from the lower apes."

"And thus the sagacious foresight of the great lawgiver of systematic zoology, Linnæus, becomes justified, and a century of anatomical research brings us back to his conclusion, that Man is a member of the same order as the apes." (Huxley.)

The Most Ancient Hunters*

The Ape-man of Java. — In 1891 there was discovered at Trinil, Java, in volcanic material (lapilli) a great quantity of mammalian bones, of species which are now all extinct in that region. Among these were the remains of the oldest known bones of ancient man. The geologic age of the fossils is somewhat uncertain, and most probably is earliest Pleistocene. The human remains consist of the upper part of the skull, or cranial vault, three molar teeth, and the entire left femur. Dubois, the discoverer, named this human being *Pithecanthropus erectus*, which means *the ape-man who walked erect* (Figs. 515, 516). The skull is of the long-headed (dolichocephalic) type, and has a low crown with prominent brow-ridges, the forehead is more receding than that of the chimpanzee, and the volume of the brain cavity is approximately 28 ounces. The largest cranial capacity in the higher apes does not exceed 20 ounces, while that of a normal living human is never less than 30 ounces. As the

* An interesting book in this connection, and one from which much of the information in this section is taken, is *Ancient Hunters*, by W. J. Sollas.

average human brain has a capacity of about 49 ounces, it is seen that *Pithecanthropus* must be included within the human family, and in his mental evolution had risen far higher than halfway between the apes and modern man. He is probably not in the direct line to the higher types of man, but represents a specialized and unprogressive branch which became extinct in the Pleistocene (Smith). The

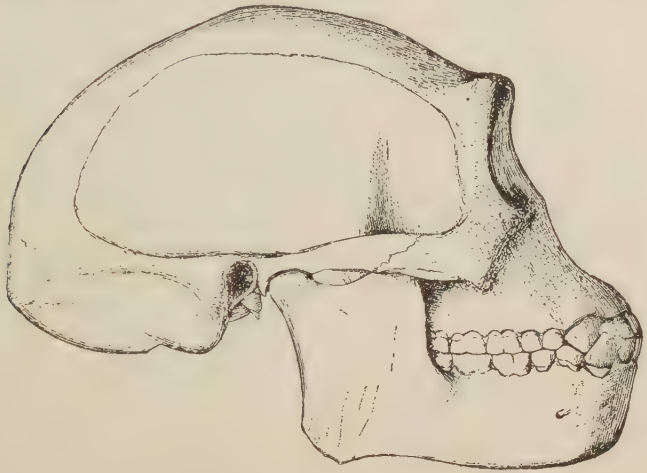


Fig. 515. — Skull of *Pithecanthropus*, the ape-man, as restored by Dubois.

femur is distinctly human, of a being that walked more or less erect, and in all probability possessed a foot very much like that of living man. The brain cavity also shows that the ape-man had probably acquired the rudiments of vocal speech. *Pithecanthropus* is estimated to have stood 5 feet 6 inches high (Fig. 516).

Eoanthropus of England. — In 1913 there was brought together the greater part of a human skull and jaw found in the plateau gravels at Piltdown, near Fletching, in Sussex, England. These remains are the oldest known of the human family in Europe and have been named the "dawn man" or *Eoanthropus*. The fragments have been carefully set together and the greater part of the skull restored by Smith Woodward of the British Museum (Pl. 39, Fig. 1, and Pl. 40, Fig. 2). The lower part of the face is decidedly prognathous or "snouty," the forehead, though narrow, is not receding, and is as steep as in modern man, the brow ridges are feeble, and the brain case is very thick, with a cavity content of nearly 43 ounces. The size of the brain, therefore, compares favorably with that of the average European, which has a content of about 49 ounces. The skull is low in proportion to length (brachycephalic), and even though

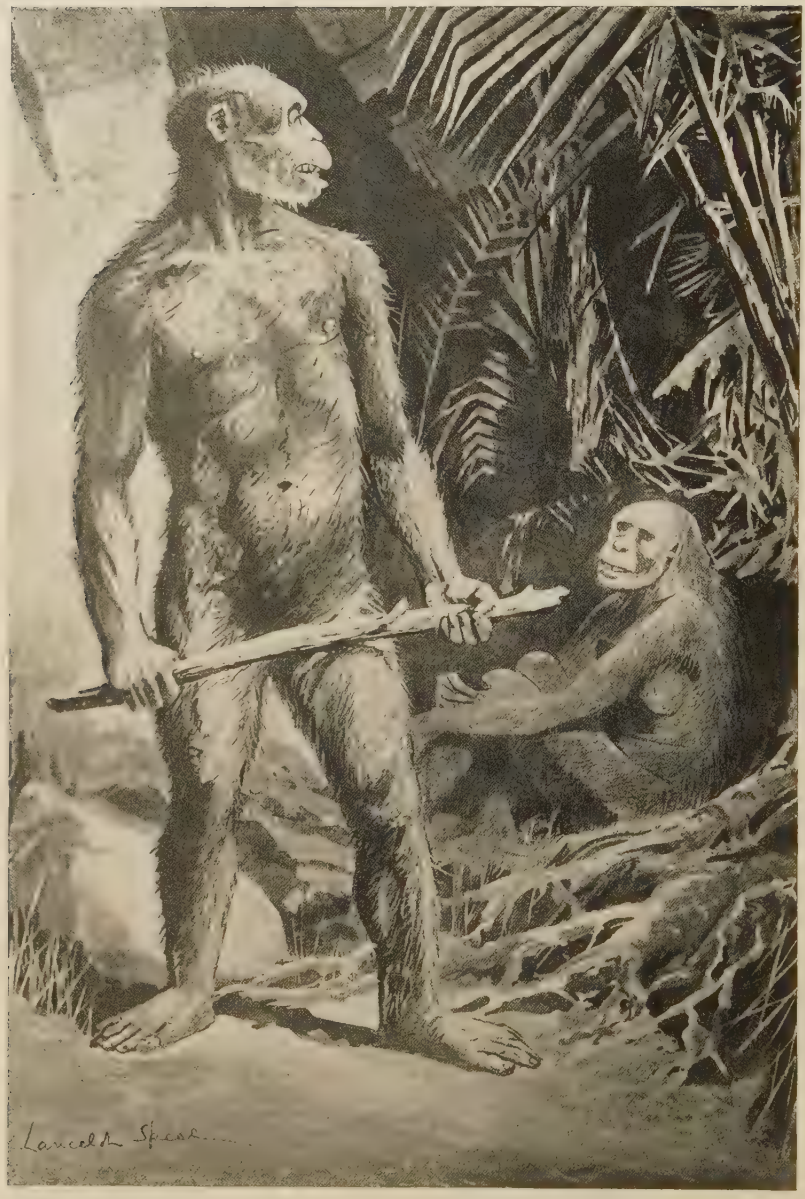


Fig. 516. — Restoration of *Pithecanthropus* by L. Speed, from Knipe's *Nebula to Man.*

it is archaic, is truly human; but the chinless lower jaw, with its large canines, is distinctly simian and very much like that of a young chimpanzee, and the neck is very thick. This strange creature, therefore, combines a human brain case with an ape's jaw. It was probably able to speak, though in a rudimentary fashion.

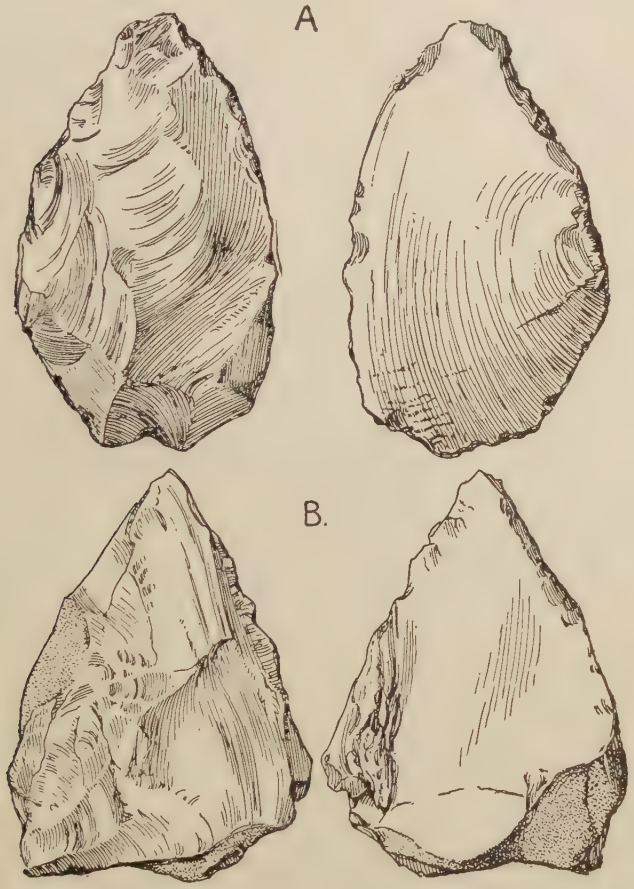


Fig. 517. — Two primitive Paleolithic flint implements associated with *Eoanthropus*, two-thirds nat. size. Each shows a coarsely flaked face and a simply flaked face. After Woodward, from British Museum Guide.

The prognathous face and powerful jaws, with their large teeth, especially the canines, show that *Eoanthropus* was a human brute, hunting and defending himself in the main with his fearful biting mouth. He was still a primitive slayer, though keener than any of his animal associates, and was destined through the manufacture of better implements to become a hunter of a higher order.

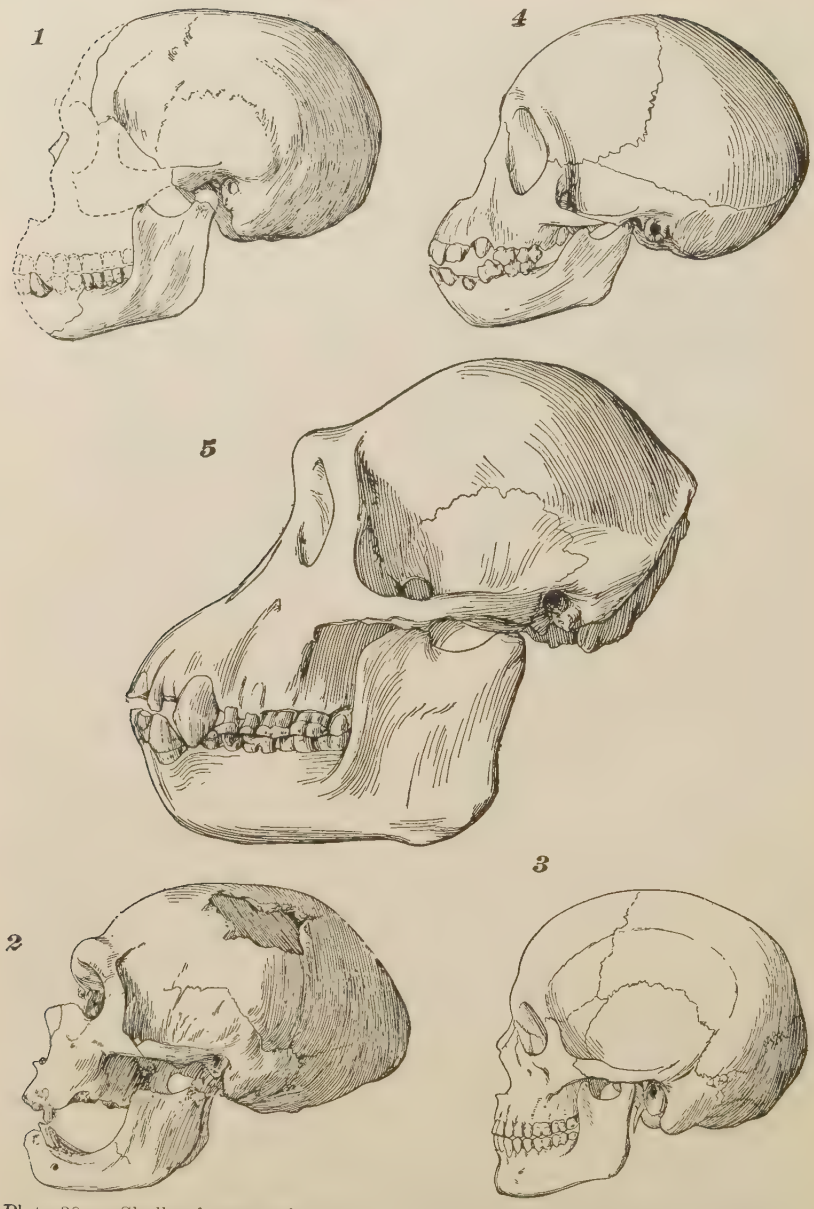


Plate 39. — Skulls of man and apes. 1, *Eoanthropus;* 2, Neandertal or Mousterian man; 3, modern human; 4, young chimpanzee without brow-ridges and more like *Eoanthropus;* 5, adult chimpanzee with marked brow-ridges and more like Neandertal man. After Woodward, from British Museum Guide.

With *Eoanthropus* were associated very ancient types of Paleolithic implements (Fig 517). The age of the plateau gravels is thought to be of the second interglacial warm time, when the hippopotamus lived in England; this is about early Middle Pleistocene (Fig. 512).

Attention should be directed here to Smith Woodward's statements that at least one very low type of man with a high forehead was in existence in western Europe long before the low-browed Neandertal man (page 971) became widely spread in this region. Accordingly he inclines to the theory that the Neandertal race was a degenerate offshoot of early man and probably became extinct, while surviving modern man may have arisen directly from the primitive source of which the Piltdown skull provides the first discovered evidence.

Heidelberg Man. — In 1907, at Mauer, Germany, not far from Heidelberg, there was found a well-preserved human jaw with all of the teeth (Pl. 40, Fig. 3). It was buried about 80 feet beneath the surface in river-deposited sand of early Middle Pleistocene age and possibly of the second interglacial warm time (Fig. 512). More recently eoliths (see below) have been found in the same stratum that held the jaw. The teeth, while powerful, are distinctly human, but the jaw bone is massive and broad and clearly more like that of an anthropoid ape. This man had no chin and was probably most closely related to *Eoanthropus*.

Eoliths. — In many places have been found large and small stones, chiefly of flint, that have rudely chipped edges and resemble weapons made by primitive man. They are found in strata of various ages as far back as the Oligocene, a time when no human being existed or for that matter any animal making stone implements. For this reason most archeologists look upon them as flints fractured by nature through such causes as rock pressure, temperature changes, or wave-pounding in the littoral of the sea.

In the ape-man, with dawning intellect, pebbles may have at first served as missiles or even as hammers. The mere striking together of stones and especially the brittle flints would lead to the discernment of cutting edges and the production of flakes that could be used for scraping, sawing, and sundering flesh and skins. At first such implements would be no better than those made by nature, and to separate the artifacts from those made through natural causes is most difficult.

No weapons have been found associated with *Pithecanthropus*, but primitive paleoliths occur in the same strata that furnished the remains of *Eoanthropus*, and "eoliths" were associated with the Heidelberg jaw. If the "eoliths" are really weapons, then most of these men must have been chippers of flint stones and makers of very rude tools (see Fig. 512).

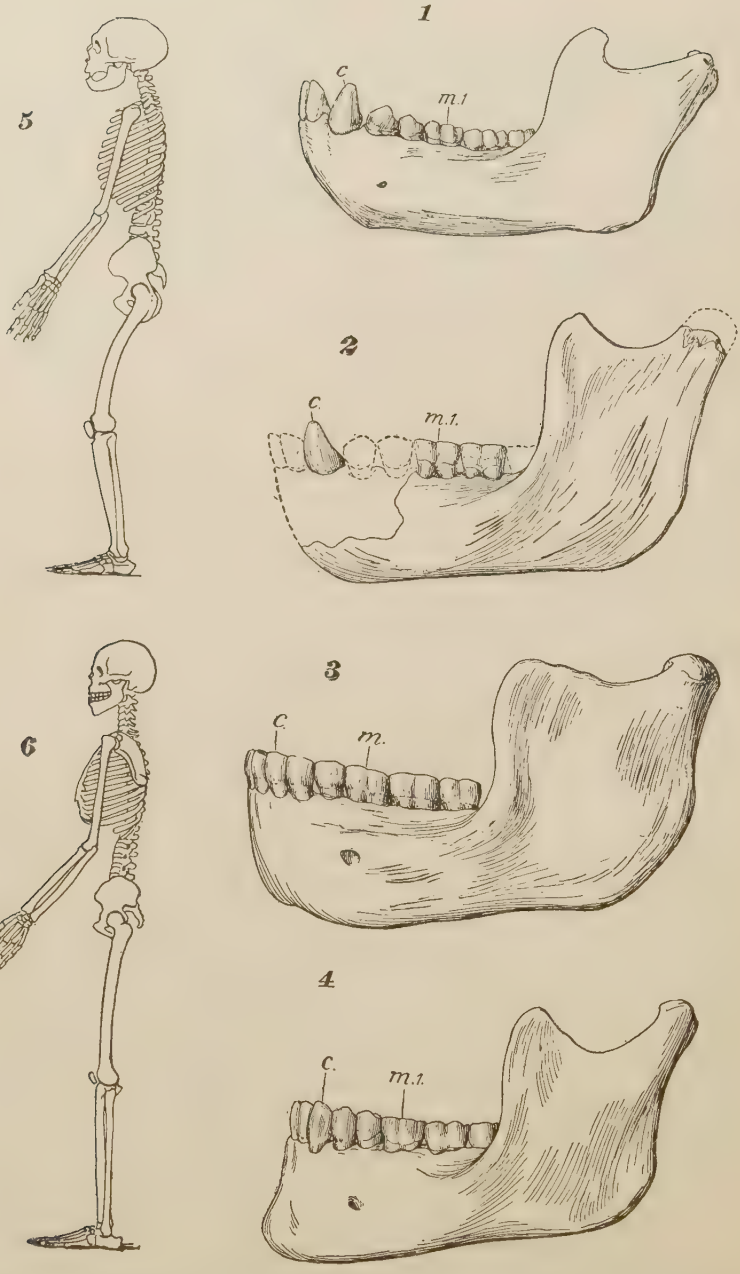


Plate 40. — Left outer sides of lower jaw of chimpanzee (1), *Eoanthropus* (2), Heidelberg man (3), and modern man (4). *c*, canine teeth; *m. 1*, first molar teeth. Diagrammatic restoration by Boule of skeleton of Neandertal man (5), and of living Australian man (6). After Woodward, from British Museum Guide.

Paleoliths. — It is a debatable question whether any human artifacts are older than the early Middle Pleistocene and the earlier questionable implements may for the present be disregarded. The oldest undoubted human artifacts are known as Paleolithic implements and among these the older Paleolithic ones are very crude in workmanship (Fig. 517). They are nodules of flint, reduced to the required shape and size by flaking with the hammer-stone, by means of oblique blows delivered to the right and left. These crude artifacts are short, thick, and irregular in form, with variable but comparatively small conchoidal fractures where the flakes were detached. The flakes obtained as by-products could also be used for small implements. For the greater part they are rude scrapers and knives, and none appear to be weapons of the chase, though their makers may have had rude wooden spears. The Neandertal men showed far more skill in the making of their artifacts, for they knocked quite large thin flakes (up to 7 inches in length) from the flint nodules and then trimmed these into the desired shape for lance-heads by finer secondary and tertiary chipping. These tools were made by the men of the Stone Age, men who were learning how to hunt animals for food and to defend themselves by their greater skill in the invention and use of improved killing devices (see Fig. 512).

Men of the Stone Age

The Older Paleolithic Hunters

Neandertal Man. — In 1856 most interesting human remains were found in a cave in the little valley known as the Neandertal, lying between Düsseldorf and Elberfeld. Since then more than fifteen other men, women, and children of this race have been found in caves and rock shelters in Belgium, France, Gibraltar, and Krapina in Croatia (Pl. 39, Fig. 2, and Pl. 40, Fig. 5). Their implements, however, are found scattered throughout western Europe and eastward into Poland, the Crimea, and Asia Minor. In France these people are known as the Mousterians and they are thought to have been the first who dwelt in caves. They lived during the last glacial episode when the climate was cool and finally cold, a time estimated to be anywhere from 60,000 to 150,000 years ago. It was the time of the bison, horse, reindeer, and mammoth, on all of which the Neandertal men subsisted. The race lived for a long time geologically (Fig. 512).

The Neandertal people (*Homo primigenius*) were a savage-looking race of stout build, short stature, averaging about 5 feet 3 or 4 inches,

with legs slightly bent at the knee, and with disproportionately large heads (Pl. 40, Fig. 5, and Fig. 518). They made fairly good stone implements and knew how to kindle a fire, for hearths occur in their cave abodes. The Australians and Tasmanians of to-day, the "most archaic types" of humanity, are their nearest relatives, and yet these savages are not descended from the Neandertal men of Europe. Huxley in 1863 said that Neandertal men possessed the most ape-like head then known, but that they were in no sense intermediate between men and apes.

The face was singular, savage, usually more or less prognathous, and unlike that of any existing race. The nose was of unusual size

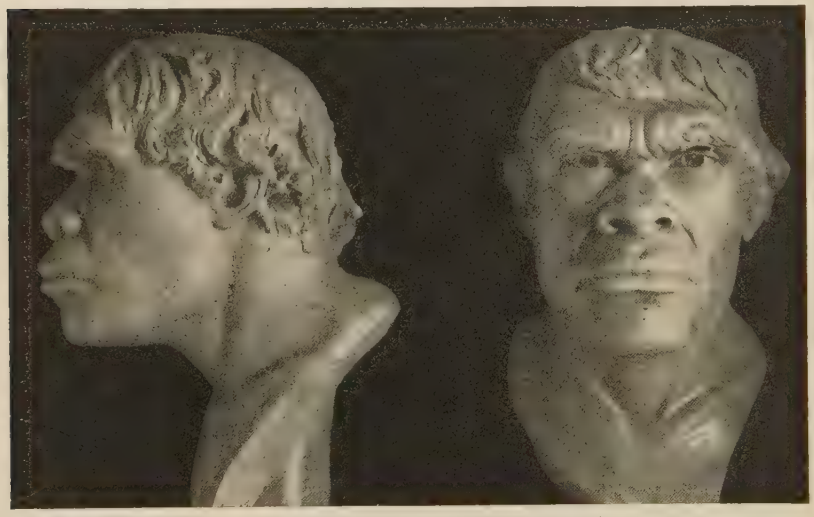


Fig. 518. — Restoration of the head of Neandertal man. Modeled by Mrs. H. Hyatt Mayer.

and wide, the upper lip very wide, and at the base of the forehead there was a very prominent and continuous brow-ridge that extended from temple to temple. It is the latter character, in fact, that distinguishes the Neandertal man from all others, though in some of the Australians a brow-ridge is also developed to a small extent. The lower jaw is heavy and massive and, as in the apes, is without a chin. The brain was unusually large. The Gibraltar head, possibly of a woman, has a capacity of about 41 ounces, while the average of Neandertal skulls appears to be 49 (in one it is 53) ounces. This average is therefore greater than in the Australian and not much below that of Europeans, whose average capacity is about 49 ounces. The hair was probably wavy.

In at least two cases the skeletons were found in their original burial places, and from them we learn that they were laid away with their implements, paints, and food, indicating a ceremonial interment and offerings of food and implements to assist the departed in the spirit world.

The Newer Paleolithic Hunters and Herders

Aurignacian Man. — We now come to men of the human species (*Homo sapiens*) who were still hunters but who possessed far greater skill in the making of stone and bone implements, and who also engraved and painted pictures of many kinds of animals in the caves of France and Spain. These were likewise of the "Old Stone Age" and appeared in western Europe at about the close of the Glacial Period, or at least 17,000 years ago, possibly even 50,000 years (Fig. 512). There were at least two races of them, a dominant one, the Cro-Magnon people, of tall stature, averaging 6 feet in height, with long arms, and long in the lower leg. They were remarkably long-headed (dolichocephalic), with a large cranial capacity ranging between 52 and 56 ounces. The face was short, the eye orbits were wider than long and depressed, and the brow-ridges were strong. The other, or Grimaldi race, shows negroid characters, its members being but 5 feet 2 to 5 inches in stature, with extremely elongated lower limbs, flat nose, prognathous jaw, and slightly retreating chin. They are thought to be allied to the living Bushmen of Africa.

The Aurignacian races appeared throughout Europe at a time when the climate was colder than it is now and when the Neandertal men were vanishing. The animals of the chase living at that time were largely the reindeer and horse, and for this reason it is also spoken of as the epoch of the reindeer. The Aurignacian implements are of the Newer Paleolithic type, that is, the workmanship of the flints is better and constantly improves with time, and the race had many more kinds of tools to serve more purposes. They also used bone for awls and ivory for skewers and ornaments, and made spears, bows and arrows, and fur garments. Themselves they ornamented with marine snail shells and teeth of mammals, and later with beads, bracelets, and other objects manufactured out of shell and ivory.

Armed with better weapons of the chase and a wider knowledge of their use, the Aurignacians were able to take better advantage of their environment. Under these circumstances, they had more ease and time for reflection, and we witness in them the birth of the fine arts. Sculpture and drawing appear almost simultaneously, and later

comes painting. This art we find preserved in the caves of France and Spain, the art of one period being overlaid by that of later times, and as time goes on the workmanship is greatly improved. Animals of many kinds are depicted, at first outlined in black (Fig. 519), then engraved on the walls and even on the ceilings of the dark caves; later were added polychromes in red, brown, black, and several shades of yellow. The pigments were of mineral origin and were mixed with grease. These artists also engraved animals on stone, bone, and ivory. The human figure appears only in the later paintings, and in these, garmented women are seen herding cattle and men chasing wild animals. Small figurines made of ivory and limestone, and usually representing nude women, are of still greater antiquity.

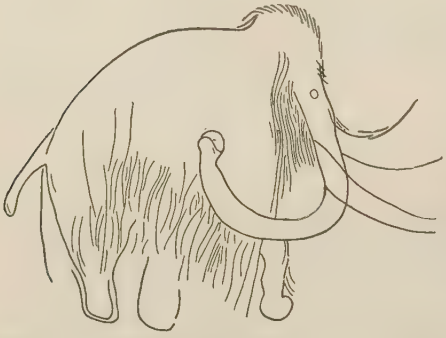


Fig. 519. — Painting of mammoth on cave wall at Combarelles, France. From MacCurdy.

Magdalenian and Later Races. — The Aurignacians were followed by the Solutréans and Magdalenians, or men of the Neolithic or polished stone period. These people not only made the same implements as the Aurignacians, but fashioned even better chipped flints and softer stones that were rubbed smooth and sometimes polished; the polishing, however, was due to use rather than to any shaping or preparatory process. The history of the race goes back perhaps 10,000 years, and while they too were hunters, they herded cattle, sheep, and goats, and somewhere about this time farming of plants for food had its origin.

The use of metals first arose in Egypt about 5000 years ago, when copper implements and ornaments were made. This period was the *age of copper*, and it was followed some 1500 years later by the *age of bronze*. The *age of iron* had its rise in Palestine about 3200 years ago and the use of the metal then spread into India and to the Mediterranean peoples. Great advances were made when humanity learned how to burn coal, and the *age of coal* began in England in the fifteenth century A.D. The last century saw the rapid development of the steam engine and we are now in the *age of electrical devices*.

Man in North America. — Nothing is known of man in North America during the Pleistocene. The red men or Indians probably migrated from Asia by way of Siberia to Alaska, and after the ice of the Glacial Period had melted away from the northern lands spread

south into Central and South America. Man has been in North America probably some tens of thousands of years, though most anthropologists believe he has been present only a few thousand years.

Birthplace of Man. — It is as yet impossible to say positively where man's transition from the ape to the human form took place. The oldest known relics of ape-man are the bones of *Pithecanthropus* found in Java, and for this and other reasons it has long been held that the race probably arose in Asia and in the cooler climes rather than in the tropical jungle. We have seen that much of central Asia was being elevated in Miocene time and that the great Himalayas rose yet higher in the Pliocene and are still rising. This time and region were, then, critical for organisms, as the climate was changing from that of the tropics to cooler and finally cold conditions, bringing on great changes among the plants and thus reacting upon the animals. Man's ancestors, therefore, had to adapt themselves to these changing conditions, and to protect themselves against the cold, clothed their bodies in the skins of the chase, and because of this covering lost their bodily hair. In addition, they had to adapt themselves to the animals and plants that remained, and many of these are not only still living in this region, but are now our domesticated animals. The ox (*Bos primigenius* into *B. taurus*), sheep, goat, pig, fowl, and pigeon are from India, while from wider Asia came the horse, camel, reindeer, elephant, peacock, goose, and ostrich. Still other forms reached Africa, and man there tamed the ass, domestic cat, greyhound, mastiff, and guinea hen. Of our domesticated plants the great majority are also of Asiatic origin. For these reasons it is thought that an ape line changed into man somewhere in central Asia, India, or China (Williston). However, the earlier evolution may have taken place farther west in the countries along the north side of the Mediterranean.

Résumé

Man, like all other living plants and animals, begins in a single, tiny, nucleated cell, and his further development is that of the Metazoa (page 415), and more especially that of the mammals and his nearest relatives, the apes. Something of this vastly long ancestral history is repeated in the first three months of each human being's existence and constitutes a metamorphosis even more wonderful and significant than the transformation of the caterpillar into the butterfly. This metamorphosis, beginning in the protozoan or single-celled stage, passes rapidly through others comparable to the lower forms of the Cœlenterates or hydra-like metazoans (page 408), and to the annulate, worm-like, gill-breathing ancestors of all vertebrates known as the half vertebrates (see *Balanoglossus*, page 691). Next appears the fish-like stage, when the functioning heart and the vestigial gills are comparable to the same organs in fishes; then the heart is transformed into the type seen in amphibians and next into that of mammals. At this time of development it is almost impossible to distinguish the human fœtus from that of other mammals, but the

latent ancestral history impressed upon the embryo from the very beginning goes on reproducing more or less blurred characteristics of the apes and man.

Among the mammals the human line had its origin in the lemurs of the Eocene of North America, which gave rise to the monkeys that spread over the greater part of the early Tertiary world. The European branch of monkeys, spreading into Africa, there gave rise to the small apes of the late Oligocene of Egypt. *Paleopithecus* spread across the Mediterranean land bridge and in the Miocene of Europe developed into the gibbons of the Euro-Asiatic countries. Out of the latter in late Miocene time originated the large-bodied apes, giving rise in the Pliocene to the several independent genealogies expressed in the orangs, chimpanzees, gorillas, and humans. The missing links between ape and ape-man will be recovered in Pliocene strata somewhere in Europe or in Asia.

We have seen that the bipedal ape-man *Pithecanthropus* was in existence in the earliest Pleistocene, a time estimated by geologists to be somewhere between 400,000 and 1,400,000 years back of the present. Then there is no record of human bones for a long time, but if the "eoliths" are of human workmanship they are evidence of man's presence in western Europe throughout the Pleistocene. About early Middle Pleistocene time human bones are again in evidence in England and Germany, but it is not until about 150,000 years ago that remains are common enough to make a fairly continuous record into the present. Throughout nearly all of this time the record is one of very slow mental evolution from the ape-man *Pithecanthropus*, with decided animal instincts, into *Eoanthropus*, and then into the possibly degenerate large-headed savages known as the Neandertal men, who lived in Europe for a long time (Fig. 512). Even at this early time (60,000 to 150,000 years ago) man knew how to kindle fire, and that a religious instinct was present is plain from the respect paid to the departed by laying them away in graves with ceremony. The fine arts arose with the Aurignacians about 20,000 years ago, and the modern state of human society and primitive farming had their rise about 10,000 years back of the present. Human mentality now dominates the organic world, and to it all creation will soon be more or less subservient. Invention and adaptation will eventually lead man to use and control the physical and vital forces and he will be master of himself and his environment.

To quote again from Huxley: "Our reverence for the nobility of manhood will not be lessened by the knowledge that Man is, in substance and in structure, one with the brutes; for, he alone pos-

sesses the marvellous endowment of intelligible and rational speech, whereby, in the secular period of his existence, he has slowly accumulated and organized the experience which is almost wholly lost with the cessation of every individual life in other animals; so that, now, he stands raised upon it as on a mountain top, far above the level of his humble fellows, and transfigured from his grosser nature by reflecting, here and there, a ray from the infinite source of truth."

CHAPTER LVI

EARTH HISTORY IN RETROSPECT

Development of the Earth

Origin of the Universe. — Astronomers and historians of the earth and of its life are impressed with one fact above all others, namely, the constant changeableness of the entire universe, the constant evolution of all matter. In the stars and nebulæ the changes are indeed exceedingly slow as measured by the comprehension of the human mind, but in the parts of each entity the interactions may be swift or long continued, leading to the establishment of new aggregates and even of new worlds. Stability is most enduring in the more or less condensed masses, and as these are made up of elements, they remain stable only so long as their environment is unchanged. Everywhere matter appears to be essentially alike, though varying from extremely tenuous or gaseous to condensed solid states. Accordingly the internal aggregation of the parts must vary, depending upon the disruptive state of the matter, so that the very tenuous luminous bodies give testimony of but a few elements, while the more solid ones evince essentially the same elementary constituents as those of the earth.

We see changing before our senses the radioactive elements, and further observations of the heavenly bodies convince us that all interact upon one another, changing their environment and therefore their states of internal aggregation. Great masses of matter for millions upon millions of years continue to change and condense from a gaseous luminous state to a variably solid one, a star or sun, and even though all the astronomic bodies are spaced by distances beyond human comprehension, their masses and their momentum may yet bring them close enough to exert decided attraction upon one another. When the approach is sufficiently near, the tidal interactions between the affected masses may become so great as to produce a stellar explosion of variable magnitude in one or both, and there is born a new star or a spiral nebula. Among the millions and millions of suns or stars there are probably more than a million of these disrupted bodies, the nebulæ, and each one of them is evolving toward a constellation. In this way arose the constellation of the sun, which is composed of the planets and their satellites.

Origin of the Earth. — What the cosmic history of the earth has been can only be conjectured from a study of the nebulæ and their probable evolution. This knowledge leads to the hypothesis that the earth began as a large knot of solid matter, situated in one of the arms of a spiral nebula, around which revolved in elliptic orbits innumerable smaller bodies, the planetesimals. The nucleal earth and moon in the course of millions and millions of years attracted to themselves these planetesimals and so grew from small diameters to sizes even somewhat greater than they are at present. As the earth's mass became greater and its attraction stronger so as to hold the light escaping gases, it gradually came to have an atmosphere and a limited hydrosphere.

Periodic Rising of Mountains. — The periodic readjustment in the earth-shell of North America is recorded by at least fourteen times of mountain making (Fig. 520). Eight of these, of lesser import, are the disturbances (Green Mountains, Taconic, Caledonian (in Europe mainly), Shickshockian, Quachita, Palisade-Chitistone, Sierra Nevada, and Cordilleran Intermontane), which took place during the closing stages of as many periods (Waucobian, Ordovician, Silurian, Devonian, Tennesseian, Triassic, Jurassic, and Comanchian). At each of these times folded mountains were thrown up by horizontal compressive movements in the earth-shell, and the area affected by each disturbance varied in length from at least 1000 miles to more than 1500 miles. The other six mountain-making movements are of far greater significance; these are the revolutions (Laurentian, Algomian, Grand Canyon, Appalachian, Laramide, and Cascadian), which close the six eras (Archeozoic, Early and Late Proterozoic, Paleozoic, Mesozoic, and Cenozoic), into which all geologic time is now divided (Fig. 520). These are also the " critical periods " in the history of the earth, when mountains are made in most or all of the continental masses. The lands are then highest above the strand-lines of the oceans, and as the climates are drier, cooler, or even cold, it follows that these times are also critical for the plants and animals then existing.

When the earth-shell folds, the deep-seated molten rocks follow into the zones of relieved pressure, and, rising to higher levels, inject themselves into the sedimentaries as the more or less large bathyliths, metamorphosing the enveloping rocks. Not only this, but as they rise they may melt and take into themselves the covering formations and so eventually gain the zone of fractured rocks, where the liquid magmas push through these openings to the surface, there to give rise to volcanoes and lava flows. Over and over again

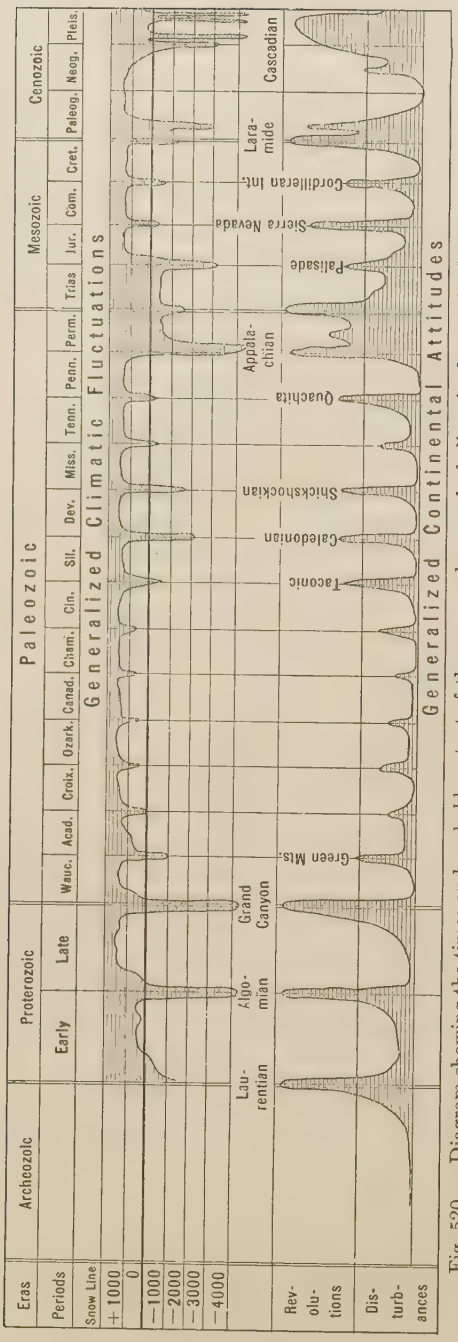


Fig. 520. — Diagram showing the times and probable extent of the more or less marked climatic changes in the geologic history of North America, and of its elevation into chains of mountains.

it is seen that volcanoes accompany mountain making and other crustal movements.

All of the young mountains of the present earth's surface are situated close to the margins of the continents or else in the areas of long enduring geosynclines. According to the law of earth wrinkling, the mountains rise out of the former sinking and loading geosynclines, the latter being the weak zones in the lithosphere and the places where the shortening of the earth-shell is taken up by folding and overthrusting. In North and South America and Africa all of the folded mountains are situated near the margins of the continents; while in Europe and more especially in Asia the young mountains are more or less marginal, but the older ones are inside of these where former geosynclines have been.

Origin of the Atmosphere and Hydrosphere. — According to the planetesimal hypothesis, there was a time when the earth's mass was too small to hold an

atmosphere. This was during the nuclear stage and before the earth had attained the size of Mars, which has a diameter of 4200 miles. When this size was reached, our planet began to hold a thin atmosphere. Ever since volcanic action began — and it is assumed to have had its origin even before the earth had attained a diameter of 3000 miles — the volcanoes and thermal springs have been adding gases and water vapor to the atmosphere. With an atmosphere present it is natural to assume the presence of a hydrosphere and areas of standing waters. However, as long as an abundance of planetesimals continued to fall in upon the earth, it is questionable if there could have been seas and ocean basins and any marked weathering processes. On the other hand, the quantity of salt in the present oceans and in the strata appears to be evidence indicating that the weathering processes and the accumulation of salt by the oceanic waters may not have begun much earlier than the Archeozoic.

Origin of Oceans and Continents. — When the earth had attained to about its present diameter, in the Archeozoic, its atmosphere gave rise to the processes of solution, to weathering of rocks, and to the washing together of sediments formed on the earth's face, and the resulting finer materials together gravitated to lower places and eventually into the oceanic basins. The latter depressions probably are primarily due to the separation of the molten magmas during the formative eon into lighter or continental and heavier or oceanic portions. Therefore the oceanic basins have as a rule tended to sink and to follow more decidedly the shrinking centrosphere, thus becoming the negative areas, while the lands, somewhat lighter in specific gravity, become more so through the solution processes, resulting in the rising protuberances of the lithosphere, the positive areas. Even though the oceans have continued to attain greater depth, the increasing volume of sediment and water has demanded enlarging basins, and some of the required space has been taken from the continents. In this way the great northern transverse continent, Eria, and the similar medial one, Gondwana, were transformed into the longitudinal continents of the present.

Permanency of Oceanic and Continental Areas. — Since the beginning of Paleozoic time the oceanic basins and the continental masses have been more or less permanent. The permanency, however, is not rigid but is rather flexible, most rigid in the oceanic areas and more flexible in the continental masses. There is, moreover, a periodic flexibility in the oceanic areas, for many times have they

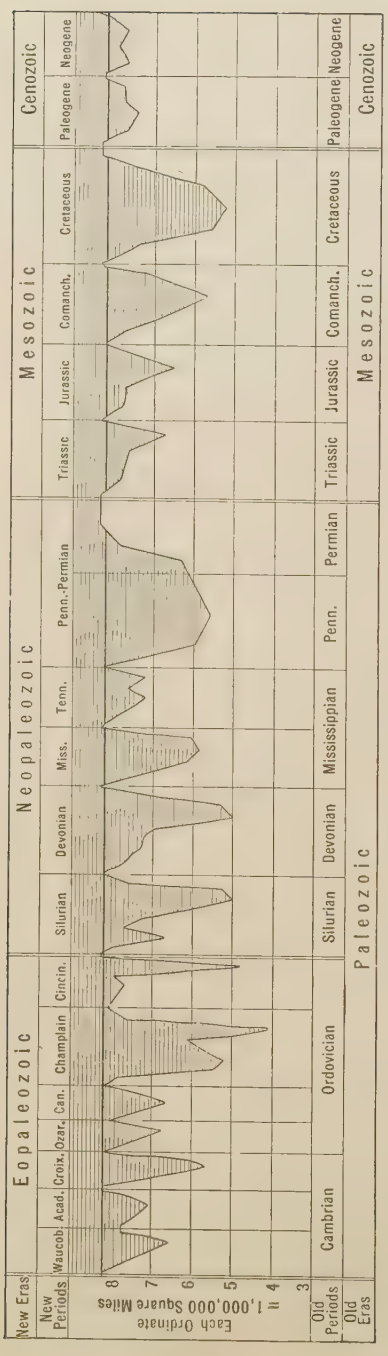


Fig. 521.— Diagram showing the time and extent of the known floods that have inundated North America since the close of the Proterozoic era.

spilled their waters widely over the land in shallow inundations. Over and over again the flooded lands have reasserted themselves above the general water-level because of renewed oceanic subsidence and the withdrawal of the waters. These are the main features in the present theory of the permanency of continents and oceans, a hypothesis that is less rigid than the original one of Dana (1846).

Periodic Continental Flooding. — Between the comparatively short intervals of mountain making and crustal unrest occur the long times of erosion, peneplanation, and more or less flooding of the continental masses by the oceans. Since the close of the Proterozoic, North America, and especially the United States, has been widely flooded by warm and shallow marine waters at least twelve times (Cambrian, Ordovician, Cincinnatian, Silurian, Devonian, Mississippian, Pennsylvanian, Triassic, Jurassic, Comanchian, Cretaceous, and in an oscillatory way during the Tertiary), and probably not less than seventeen times (two additional floods in the Cambrian, two in the Ordovician, and one in the Mississippian). These shallow-

water spreadings begin in a small way, grow to greater dimensions throughout a very long time, and then, declining, recede far more rapidly than they came. They vary in areal extent up to 4,000,000 square miles (Fig. 521).

During the Paleozoic nearly all the seas were of the epeiric kind, with the greatest spread of water first from the Arctic, next from the Pacific, and in least amount from the Atlantic. On the other hand, the number of floods was greater from the south than from the north, and the waters were most persistent in the Appalachian and Cordilleran subsiding geosynclines, the sites on which eventually arose the Appalachian and Rocky Mountains.

Imperfection of the Geologic Record. — It is a well-known fact that the geologic record is fragmentary and local in preservation and that even after correlating all the parts and through them restoring the events of the geologic past for the entire world, the final result, the geological time-table, still remains very imperfect. How incomplete the records are in Stratigraphic Geology is made clearer from one generation of geologists to another, since where seventy years ago geologists knew of but three eras, there are now held to be six; and in the same time the number of known periods has more than doubled. As the major time divisions have been doubled in number in seventy years, it is apparent how inadequate must be our knowledge of the entire earth history. In another half-century the geological time-table will doubtless be again as long as it is now, but this perfecting of knowledge will probably not come through the discovery of many more new eras and periods, but rather through the finding of many more of the minor time elements, the formations, which go to make up the systems of rocks. The long middle times of the periods are even now far better known than are the opening and closing events of these divisions.

Age of the Earth. — From the preceding statements, it follows that any estimates as to the age of the earth stated in years and based upon the known sedimentary record can not be much better than guesses. Further, we do not yet know satisfactorily the rate of erosion or sedimentary accumulation. Data have been gathered as to the mean annual rate of sedimentary discharge for nine rivers and it varies between 1 part of sediment in 291 of water for the Rio Grande and 1 part in 10,000 for the Uruguay. Harker states: " The highest figure is thus thirty-four times as great as the lowest " and " a mean of nine figures so discordant can not afford any information of quantitative value."

Hutton, one of the founders of Geology, said more than a century

ago that geologic time had no "vestige of a beginning, no prospect of an end." In other words, that geologic time was infinite. A reaction from this belief came in 1862 from the physicist, Lord Kelvin, who held that as our planet was continually losing energy in the form of heat, the globe was a molten mass somewhere between 20,000,000 and 400,000,000 years ago, with a probability of this state occurring about 98,000,000 years ago. Finally in 1897 he concurred in Clarence King's conclusion that the globe was a molten mass about 24,000,000 years ago. Both of these conclusions, however, were wrought out under the Laplacian hypothesis, and now many geologists hold that the earth never was molten. While geologists have not been able to fit their evidence into so short a time, they have ever since been trying to keep their estimates within the bounds of Lord Kelvin's older calculations. Walcott, in 1893, on the basis of the stratigraphic record and the known discharge of sediment by rivers, concluded that 70,000,000 years had elapsed since sedimentation began in the Archeozoic. Sir Archibald Geikie places the time at 100,000,000 years, and most geologists have tried, although with difficulty, to fit the record within these estimates.

Since the discovery of radium, all of the calculations previously made have been set aside by the new school of physicists, and now geologists are told that they can have 1,000,000,000 or more years as the time since the earth attained its present diameter. "A study of the various radioactive elements contained in minerals and rocks," says Harker, "has shown that it is possible, in certain favorable cases, to calculate directly their age in years." Thus it has been estimated that the Eocene iron-ores of Antrim in Ireland are 30,000,000 years old, and that those of the Carboniferous limestone of Cumberland, England, are 140,000,000 years in age. The igneous rocks of Devonian time about Christiania, Norway, show an age of 185,000,000 years, while "Archean" rocks have values ranging between 1,000,000,000 and 1,600,000,000 years. Even if finally it shall turn out that the physicists have to reduce their estimates as to the age of certain minerals and rocks, geologists nevertheless appear to be on safer ground in accepting their estimates than those based either on sedimentation, chemical denudation, or loss of heat by the earth.

Climatic Variations. — We are living at a time when the earth has marked climatic differences, varying between very cold polar climates and hot moist or dry tropical conditions. This has, however, not always been the case, for not long ago geologically the temperature was even colder than it is now, and most of the climates

of the past have been warm and fairly equable the world over. The warm climates persisted during long geological ages, and even though there were zonal belts and fluctuations in the temperature, the polar areas were usually inhabited by plants and animals of kinds that were addicted to winterless environments. These temperature fluctuations were greatest during the closing and opening stages of the periods, and the atmosphere was then also often drier (Fig. 520).

The long warm times were separated by short periods of cool to cold climates. Geologists now know of seven periods of decided temperature changes (earliest and latest Late Proterozoic, Silurian, Permian, Triassic, Cretaceous-Eocene, and Pleistocene) and of these at least four were glacial climates (both Proterozoic times, Permian, and Pleistocene). The greatest intensity of these reduced temperatures varied between the hemispheres, for in earliest Late Proterozoic and Pleistocene time it lay in the northern, while in latest Proterozoic and Permian time it was more equatorial than boreal. Cooled climates occur when the lands are largest and most emergent, during the closing stages of periods and eras, and cold climates nearly always exist during or immediately following revolutions, when the earth is undergoing marked mountain making.

Progress of Life on the Earth

Appearance of Life. — We have seen that the earth began to hold a thin atmosphere when it had reached a diameter of about 4200 miles, but it is not known whether there were then or for a long time afterward standing bodies of water permitting life to originate in them. Further, it is not known what the temperature then was, or whether it was equable enough for life to have existed. Under these circumstances it is useless to speculate on the origin of life or what its nature may have been previous to the Archeozoic, the time when the geologic record begins.

Life of the Archeozoic and Proterozoic Waters. — At the very base of the geologic record, in the Archeozoic, the rocks testify to a world with about the same physical environment as that of subsequent time. There were oceans and continents, an atmosphere charged with water vapor and carbon dioxide, erosion and solution materials, and the formation of mudstones, sandstones, limestones of vast thickness, carbonaceous shales, graphites, and iron-ores. There are, however, no discernible or undisputed fossils, but that life was present in the marine waters is attested by the carbonaceous shales and the great amount of graphite. It is therefore assumed that the Archeozoic, the " Age of Unicellular Life," was a world of

organisms composed in the main of Protophyta and Protozoa. As Archeozoic time was very long, the unicellular life of the earlier ages could readily have evolved into higher forms in the later periods. It is therefore postulated that there were also many tiny forms of multicellular plants and animals present in the later Archeozoic. Among the latter were globules of cells resembling minute mulberries (morulæ), little hollow sacs with the cells arranged in two layers (external and internal) like the well-known planulæ and gastrulæ of the living world, and more complicated structures, the beginnings of the higher animals that have a true body cavity (cœlomate larvæ). (See Fig. 522.)

Throughout the Proterozoic rocks, known marine fossils are indeed scant, and yet we have learned more of Proterozoic fossils in America through the researches of Walcott during the past fifteen years than from the previous endeavors of all other geologists. The harvest, however, is still small, but we can say that we know of an abundance of marine algæ, some radiolarians, and tubes and burrows made by annelids. If we knew no more than of the occurrence of annelids, this would be a great deal, for their presence in the Proterozoic means the existence of the more lowly organized sponges, cœlenterates, and worms. However, that there were many other kinds of marine invertebrates is indicated by the highly varied life found in the oldest Cambrian strata. In fact, the opening period of Paleozoic time shows that more fundamental evolution among the marine invertebrates had taken place up to this time than subsequently. (See Fig. 522.)

Paleozoic Marine Life. — In the Lower Cambrian we find established all of the main phyla of invertebrates, and as the fishes appear in advanced forms in the Middle Ordovician, it follows that even the vertebrates had their origin previous to that time. Moreover, the trilobites are members of the highest phylum of invertebrates, the arthropods, and are hence the highest expression of skill and intelligence in a most ignorant world of invertebrates (Fig. 522).

In the Ordovician seas appear the agile carnivorous cephalopods and the first fishes. With the rise of the former goes the decline of the defenseless trilobites, and slowly they pass out of existence, vanishing altogether with the Paleozoic. The active cephalopods rise into dominancy in the Ordovician and Silurian, when the fishes are beginning their ascendancy, and even though the former do not represent the highest type of animal evolution and mentality, in the later Paleozoic they still continue to evolve into the goniatids and the highly varied ammonids, that in turn persist to the end of

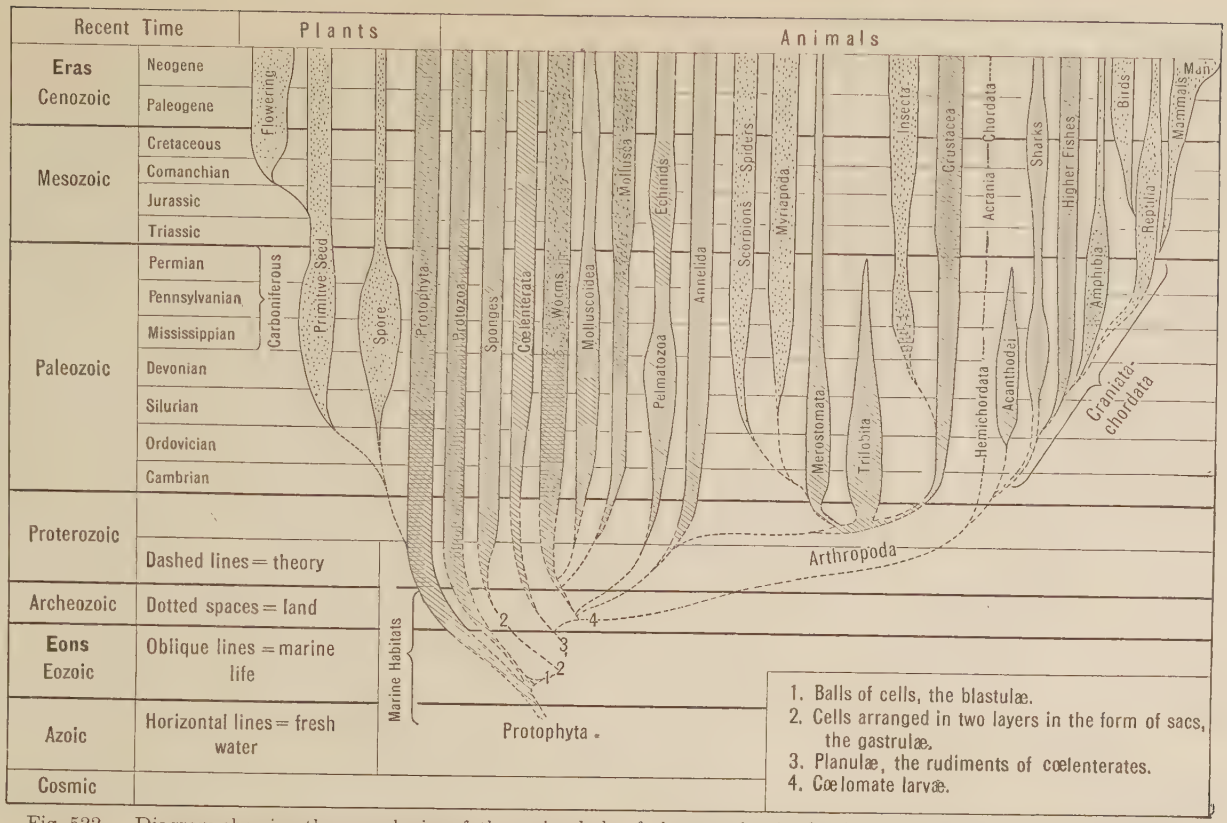


Fig. 522. — Diagram showing the genealogies of the main phyla of plants and animals, their appearance and duration in time, and their essential habitats.

Mesozoic time. The vast majority of Paleozoic marine animals, however, are sessile and vegetative and feed upon the microscopic bios that is brought to them by the water currents and other fainter currents generated by the organisms themselves. The bottom-living sea-weeds furnish food for the prowling vegetarians.

Rise of Land Floras. — So far we have been tracing the evolution of life in the seas and oceans; now we must take up the appearance of organisms on the lands, and first, of the land floras. Previous to the Ordovician we know of no land plants and the vascular or woody kinds appear for the first time toward the end of this period. It is not, however, until the Middle Devonian that they are sufficiently common to enable us to speak of land floras. Then we learn that evolution among them had progressed far, for trees are present, some of which must have been 30 or more feet tall. This, the first land flora, goes on evolving and in the Pennsylvanian attains its maximum development in variety and stature. Our knowledge of the vegetation of this time, however, is restricted to that of the lowlands and the swamps, and practically nothing is known of the upland floras. They are in the main spore-bearing plants, of rapid growth and with soft and spongy woods; while many kinds of seed-bearing shrubs and trees are present, their flowers are small and unattractive. Among the lycopods occur great trees over 100 feet tall, with trunks reaching more than 3 feet in diameter. The climate of the time is warm and moist, and as spores are microscopic and therefore very light, the winds carry them everywhere, with the result that the plant assemblages of the Pennsylvanian are world-wide in distribution and the flora is hence spoken of as cosmopolitan. (See Fig. 522.)

In the Permian the greater part of this interesting mild climate flora is either destroyed or forced to evolve into hardier kinds because of the ice age of the time. A new flora then arises in the southern hemisphere, consisting in the main of modern ferns, conifers, and cycads. It is at home on Gondwana Land and develops into the second cosmopolitan flora, which dominates the earlier half of the medieval world. Finally, the modern flora takes possession of the world early in Cretaceous time. With it come beautiful flowers, sweet odors and honey, a greater abundance of fruits and nuts, and consequently better homes and more varied foods for an enlarging world of insects, reptiles, birds, and mammals. Finally, in the early Tertiary the grasses and cereals take their ascendancy, and since the Miocene grassy plains have been plentiful and on their bounty has developed a new world of grazing mammals (Fig. 522).

Rise of Insects. — The water-breathing Paleozoic trilobites gave rise, it is thought in the Devonian or possibly even earlier, to the air-breathing insects, but none of the latter are as yet known before the Pennsylvanian. This earliest insect world, still largely addicted to a water habitat in its larval growth, was a strange one of very large forms, some resembling dragon-flies, one of which measured 29 inches across the wings, while most of them were ancestral or actual cockroaches, the giants attaining a length of 4 inches. They were carnivorous and herbivorous in habitat and developed to maturity without passing through a series of larval changes. The cold climate of the Permian, however, overwhelmed them as it did the spore flora. In the struggle for existence only those stocks of insects remained that had learned how to hibernate through the winters and in their adaptations were transformed into new orders. They were the ones that first introduced into their life histories those wonderful metamorphoses now seen in the transformation from maggot into fly and caterpillar into moth or butterfly. With the changes in the Mesozoic floras went other modifications in the insects, and with the rise of the flowering plants, birds and mammals appeared the adaptations of honey-sucking, the pollinating of flowers, the development of body parasites, and blood feeding.

Appearance of Animals on the Lands. — We have seen that the lands were hardly fit habitats for animals before the Devonian because of the scantiness of vegetation. With the Middle Devonian, at least the moist places and the swampy areas abounded in plants and in their presence there were food and new homes for the ever-widening circles of life. In the fresh waters, however, favorable habitats for the larger organisms were established much earlier, probably even as early as the Cambrian. This statement is based on the fact that in the Middle Ordovician there occur specialized fishes, of the bony-skinned or ostracoderm type, and even though their remains occur in marine strata, it is held that they lived in the estuaries and rivers of that time. (See Fig. 522.)

Lung-fishes are known in many forms in Silurian and Devonian times, but how they changed their paired fins into the limbs of the higher vertebrates still remains unsolved. However, in the Upper Devonian rocks occurs the track of a large amphibian, testifying that this change had been made and that amphibia having the form of the living mud-puppies were then in existence. Further evidence fails us until the Pennsylvanian, where we meet with many limbed and limbless amphibia, of small size, and with armored heads, — the stegocephalians. In the Permian there are much larger forms, most

at home in water and but poorly adapted to a permanent abode on the land because of their sprawling type of limb. Associated with them, however, are many kinds of reptiles that are still amphibian in appearance, but more active, agile, and wholly restricted to life upon the dry land. This is a mighty change. Next the reptiles are struggling to conquer the lands, where there is an abundance of food, but to accomplish this fleet-footedness is a necessity. Hence the handicap of sprawling legs and belly-crawling in some forms is overcome by raising the body above the ground and supporting it upon pillar-like limbs. The need for this is heightened by the fact that the continents of later Permian time are cool or arid and therefore food and drink are scarce and long distances apart. As a natural consequence the running animals take their ascendancy in this period and later give rise among others to the dinosaurs.

Vertebrates of the Medieval World. — With the Triassic the lands were captured and completely dominated by the reptiles and more especially the dinosaurs. In the Comanchian the latter developed into dimensions and tonnage never attained before or since among land animals, for 37 tons of animated flesh made up *Brontosaurus*, the thunder saurian, and *Diplodocus*, though somewhat lighter, reached 80 feet in length. Senseless brutes they were, for their individual brains weighed about one pound. Their great mass and low mentality were their undoing, and all dinosaurs, large and small, probably vanished with the Mesozoic, at a time when greater skill was coming into the animal world.

Out of the small and agile dinosaurs arose two dynasties of warm-blooded descendants which further clothed themselves in feathers and fur respectively so that they might the more easily preserve the heat and therefore the energy of their bodies. The egg-laying mammals were the first to arise in the Triassic, while the birds, appearing in the Jurassic, have never become a dominating tribe among animals, probably because of their small bodies and light weight, so necessary for flight. On the other hand, the evolution of the mammals was slow throughout the Mesozoic and all of them remained small, maintaining themselves in obscurity, and it would appear essentially in the forested areas. With the rise of the modern floras in the Cretaceous they fared better, but not until the dinosaurs vanished did they come forward as the dominating force among organisms. (See Fig. 522.)

Rise of Giants. — Ever since the Cambrian the organic world has had its pygmies and giants. The healthy mean among animals and the rise of new stocks lie among the small and unobtrusive, and the

vital world of any time may be divided into three categories: the static or slightly changing, the active progressives, and the sluggish and lazy, leading into the degenerates.

Large size may appear in any one of these groupings, but there is a marked tendency to increase in size among the active types, the progressives, which are constantly reaching out for more food. They rise into ever greater size, and suddenly vanishing with changed environments, leave no progeny to continue their ancestral parentage, and the other small and inconspicuous stocks take their places. This form of evolution has recorded itself so often that but a few of the more striking instances need be mentioned. The average length among trilobites is about 1.5 inches, and yet stock after stock attains to several inches and giants appear many times in forms ranging from 12 to 27.5 inches. Among the ammonites the average diameter is about 3 or 4 inches, but many are known a foot across and even as large as 7 feet, with tubes from 20 to 35 feet long. The story is similar among the fishes, ichthyosaurs, plesiosaurs, and whales of the seas and oceans, and on the lands several stocks of dinosaurs are conspicuous by their great size. Among the Tertiary mammals, there are many similar ascendancies, but we need mention only the evolution of the horses, camels, and proboscidians.

Rise of Mentality. — Mentality is of extraordinarily slow increase among the animals of the seas and oceans, and on the land, beginning with the Devonian, it is also slow, though faster than in the water. The environment in Neptune's realm is far more equable and there is no plane here in the sense of the surface of the land. Therefore the struggle for existence is far harder on the continents where the climate constantly varies and the organisms more often encounter one another. There is a steady but small increase of brain among the land vertebrates from the amphibia of the Pennsylvanian into the egg-laying mammals of the Mesozoic. The rapid development of mentality, however, comes in later Eocene time, when in most stocks of placental mammals there is increasing power of discernment and better adaptation to the environment. The culmination of the brain in size and complexity of structure is among the anthropoids, beginning in the lemurs, monkeys, apes, ape-men, and reaching its climax in man. What this difference is may be strikingly illustrated by the brain weight of man, which is about 2 pounds to 100 of flesh, contrasting with the giant dinosaurs of the Mesozoic, which had from 2.5 ounces to less than 2 pounds of brain with from 5 to 37 tons of body weight.

Our retrospect may close as it was begun, in wonderment at the ceaseless change of all things, from man to the grandeur of the face of the earth. Whence has it all come, what does it all mean, and to what great things is it all tending? These will ever remain the questions of finite man, in his ceaseless endeavor to grasp the significance of the infinite.

APPENDIX B

TECHNICAL NAMES OF THE FOSSILS ILLUSTRATED

As Historical Geology is replete with technical names of plants and animals which do not interest the undergraduate student and are of value only to the specialist, it was decided to keep them out of the main part of the book, except in the case of certain of the striking extinct organisms that have no counterpart in the living world. The teacher, however, will want to know the names of all the fossils illustrated so that he may connect his wider knowledge with the figures, and therefore the scientific names of the forms pictured in the various plates and figures are given in this appendix. Unless otherwise indicated, the figures are natural size.

Plate 1, Page 593

Fig. 1, *Holmia bröggeri*, × ⅓; 2, *Olenellus thompsoni*, × ½; 3, *Atops trilineatus;* 4, *Eodiscus speciosus;* 5, *Archæocyathus rensselæricus*, × 3; 6, *A. profundus;* 7, *Paterina bella*, × 4; 8 and 9, *Obolella crassa*, × 3; 10 and 11, *Stenotheca rugosa;* 12, *S. rugosa abrupta.*

All after Walcott.

Plate 2, Page 595

Middle Cambrian:

Fig. 1, *Paradoxides harlani*, × ¼; 2, *Dorypyge curticei*, × ½; 3, *Ptychoparia kingi*, × ¾; 4, *Agnostus montis*, × 3.

Upper Cambrian:

Fig. 5, *Crepicephalus texanus*, × ½; 6 and 7, *Owenella antiquata*, × 2; 8, *Hyolithes primordialis;* 9–11, *Billingsella coloradoensis*, × 2; 12 and 13, *Huenella texana*, × 1½; 14, *Lingulepis acuminata*, × 2.

Mostly after Walcott.

Plate 4, Page 624

Figs. 1 and 2, *Phyllograptus ilicifolius* and *P. angustifolius*, crushed flat; 3, *P. angustifolius*, about × 2, uncrushed; 4, *Tetragraptus fruticosus;* 5, *Goniograptus postremus*, × ½; 6, fragment of *Loganograptus logani;* 7, *Climacograptus bicornis;* 8, *Diplograptus ruedemanni*, × ¾; 9 and 10, *Orthis tricenaria*, × ¾; 11–13, *Dalmanella testudinaria;* 14–16, *Hebertella sinuata*, × ½; 17, *Dinorthis subquadrata*, × ¾; 18 and 19, *Platystrophia laticosta*, × ¾; 20 and 21, *Rafinesquina alternata*, × ¾; 22, *Strophomena planumbona*, × ½; 23 and 24, *Triplecia extans*, × ½; 25, *Leptæna rhomboidalis*, × ¾; 26, *Plectambonites sericeus;* 27–29, *Rhynchotrema capax*, × ¾.

In the main from the New York, Ohio, and Indiana State Surveys.

PLATE 5, PAGE 626

Fig. 1, *Modiolopsis modiolaris*, × ⅔; 2, *Pholadomorpha divaricata*, × ⅔; 3, *Colpomya constricta;* 4, *Cyrtodonta huronensis*, × ½; 5, *Pterinea demissa*, × ½; 6, *Opisthoptera fissicosta*, × ½; 7, *Byssonychia radiata*, × ⅓; 8, *Ctenodonta cingulata*, × 2; 9, *Protowarthia cancellata*, × ½; 10, *Cyrtolites ornatus*, × ½; 11, *Trochonema umbilicatum*, × ½; 12, *Eotomaria supracingulata*, × ½; 13, *Cyclonema humerosum*, × ⅔; 14, *Helicotoma planulatoides;* 15, *Maclurea logani* with the operculum, × ½; 16, *Hormotoma gracilis*, × ½; 17, *Orthoceras multicameratum*, × ⅛; 18, *Cyrtoceras juvenale*, × ½; 19, *Schroederoceras eatoni*, × ⅓; 20, *Eurystomites occidentalis*, × ¼.

In the main from the Ohio, New York, and Minnesota State Surveys. In part after Scott.

PLATE 6, PAGE 628

Fig. 1, *Cyathospongia reticulata*, × ½; 2, *Zittelella typicalis*, × ½; 3 and 4, *Streptelasma profundum*, × ½; 5, *Glyptocrinus dyeri*, × ½; 6, *Ceraurus pleurexanthemus;* 7 and 8, *Calymene callicephala;* 9, *Basilicus canadensis*, × ⅔; 10, *Isotelus maximus*, × ½; 11, *Bumastus trentonensis*, × ½; 12, *Ampyx nasutus;* 13, *Trinucleus concentricus;* 14, protaspis stage of *Triarthrus becki*, × 20; 15, protaspis stage of *Proëtus parviusculus*, × 20.

In the main after the New York, Ohio, and Illinois State Surveys. Also after Beecher and Zittel.

FIGURE 381, PAGE 630

Fig. *A*, *Protospongia quebecensis; B*, *P. coronata; C*, *P. mononema; D*, *P. tetranema; E*, *P. cyathiformis.*

After Dawson and Hinde.

PLATE 9, PAGE 667

Fig. 1, *Halysites catenulatus;* 2, *Favosites occidentalis*, × ¾; 3, *Troostocrinus reinwardti;* 4, *Eucalyptocrinus crassus*, × ½; 5 and 6, *Monomerella noveboracum*, × ½; 7, *Chonetes cornutus;* 8, *Pentamerus oblongus*, × ⅓; 9, *Rhynchotreta americana;* 10, *Spirifer crispus;* 11, *S. radiatus*, × ⅔; 12, *Hyattidina congesta;* 13, *Whitfieldella nitida*, × ½; 14, *Atrypa nodostriata;* 15, *Strophostylus cyclostomus*, × ⅔; 16, *Platyceras angulatum;* 17, *Diaphorostoma niagarense*, × ½; 18, *Ceratocephala dufrenoyi;* 19, *Staurocephalus murchisoni;* 20, *Deiphon forbesi;* 21, *Metopolichas breviceps*, × ½.

Mainly after the New York and Indiana State Surveys. Also from Scott and Zittel.

PLATE 12, PAGE 675

Fig. 1, dorsal aspect of *Eurypterus remipes*, × ⅓; 2, same, from the ventral side, female, × ⅓; 3, *Hughmilleria socialis*, × ½; 4, *Eusarcus scorpionis*, × ⅓; 5, *Pterygotus buffaloensis*, × $\frac{1}{2.5}$; 6, *Ceratiocaris.*

After Clarke and Ruedemann.

PLATE 13, PAGE 681

Fig. 1, living American gar-pike, a ganoid (*Lepidosteus osseus*), × ⅙; 2, Devonian ganoid from Scotland (*Osteolepis macrolepidotus*), × ½; 3, Upper Devonian ganoid from Scaumenac Bay, Canada (*Scaumenacia curta*), × ½; 4, Devonian ganoid with cycloid scales, from Scotland (*Holoptychius flemingi*), × ½; 5, living

marine lamprey (*Petromyzon marinus*), $\times \frac{1}{6}$, note the seven openings back of the eye, exits from the gills; also edge of circular mouth, and absence of paired fins.

Figs. 2 and 4 after Woodward, British Museum Guide Book; Fig. 3 after Hussakof.

Plate 14, Page 683

Fig. 1, Lower Devonian acanthodian shark, from Scotland (*Climatius macnicoli*), $\times \frac{1}{3}$; 2, Upper Devonian shark, from Ohio (*Cladoselache fyleri*), $\times \frac{1}{5}$; 3, living Port Jackson cestracionf shark, from Australia (*Cestracion philippi*), $\times \frac{1}{10}$; 4, living lung-fish of Australia (*Neoceratodus forsteri*), $\times \frac{1}{12}$; 5, Devonian lung-fish, from Scotland (*Dipterus valenciennesi*), $\times \frac{1}{2}$.

Figs. 1 and 5 after Woodward, British Museum Guide Book; Fig. 2 after Dean; Fig. 3 after Garman.

Plate 16, Page 707

Fig. 1, *Pentremitidea filosa*, $\times 2$; 2, *Granatocrinus leda;* 3, *Elæacrinus verneuili;* 4, *Heliophyllum halli;* 5, *Cystiphyllum vesiculosum;* 6, *Phillipsastræa gigas;* 7, *Thamnoptychia limbata;* 8, *Syringopora perelegans;* 9, *Aviculopecten ornatus*, $\times \frac{2}{3}$; 10, *Pterinea flabellum*, $\times \frac{1}{2}$; 11, *Actinodesma erectum*, $\times \frac{2}{3}$; 12 and 13, *Nucula randalli;* 14, *Goniophora carinata*, $\times \frac{2}{3}$; 15, *Orthonota undulata*, $\times \frac{2}{3}$; 16, *Modiomorpha concentrica*, $\times \frac{1}{3}$; 17, *Cypricardella bellistriata;* 18, *Grammysia bisulcata.*

From Paleontology of New York, and Geological Survey of Canada.

Plate 17, Page 708

Fig. 1, *Chonetes setigerus;* 2, *Productella hirsuta* (Upper Devonian); 3, *Tropidoleptus carinatus;* 4 and 5, *Eatonia medialis;* 6 and 7, *Camarotœchia ventricosa;* 8 and 9, *Gypidula coeymansensis;* 10, *Meristella lævis;* 11, *Atrypa reticularis;* 12, *A. spinosa;* 13, *Spirifer pennatus* (*mucronatus*); 14, *Spirifer medialis;* 15, interior and exterior of ventral valve of *Spirifer arenosus;* 16, *Ambocœlia umbonata*, $\times 2$; 17, *Athyris spiriferoides;* 18, *Rensselæria ovoides.*

From Paleontology of New York.

Plate 18, Page 709

Fig. 1, *Oxyclymenia undulata* (Europe); 2, *Aphyllites vanuxemi*, $\times \frac{1}{3}$; 3, *Prolecanites lunulicosta* (Europe), $\times \frac{1}{2}$; 4, *Tornoceras simplex* (Europe); 5, *Brancoceras sulcatum* (Europe); 6, *Manticoceras oxy*, $\times \frac{1}{6}$; 7, *Odontocephalus selenurus*, $\times \frac{1}{4}$; 8 and 9, rolled-up *Cryphæus punctatus*, and same distended (Europe); 10, *Phacops bufo;* 11, *Dipleura dekayi*, $\times \frac{1}{2}$; 12, *Terataspis grandis*, $\times \frac{1}{12}$.

Figs. 1–5, 9, 11 from Gürich's *Leitfossilien;* Fig. 8 after Richter; Figs. 6, 7, 10, 12 from Paleontology of New York.

Plate 20, Page 735

Figs. 1 and 2, *Endothyra baileyi*, $\times 9$; 3, *Axinura canadensis*, $\times \frac{1}{2}$; 4, *Brancoceras ixion*, $\times \frac{1}{2}$; 5, *Melonechinus multiporus*, $\times \frac{1}{3}$; 6, *Pentremites conoideus;* 7, *P. elongatus;* 8, *Agassizocrinus dactyliformis*, $\times \frac{2}{3}$; 9, *Platycrinus symmetricus;* 10, *Batocrinus pyriformis*, $\times \frac{2}{3}$; 11, *Agaricocrinus bullatus;* 12, *Forbesiocrinus wortheni*, $\times \frac{2}{3}$; 13, *Onychocrinus ramulosus*, $\times \frac{2}{3}$; 14, *Cyathocrinus multibrachiatus.*

In the main after the Indiana State Survey.

Plate 22, Page 752

Fig. 1, *Stenodictya lobata;* 2, *Eubleptus danielsi,* × 1½; 3, *Eucœnus ovalis;* 4, *Aphthoroblattina johnsoni,* × ⅕; 5, *Eophrynus prestwichii,* × 1½.

Figs. 1–4 after Handlirsch.

Plate 23, Page 756

Fig. 1, *Triticites secalicus,* × 2; 2, same cut through center, × 8; 3, *Chonetes mesolobus;* 4, *C. verneuilianus,* × 2; 5–7, dorsal and ventral valves, and dorsal interior of *Productus nebraskaensis;* 8 and 9, *P. punctatus,* × ⅔; 10, *P. semireticulatus;* 11, *P. cora,* × ½; 12, *Spirifer cameratus,* × ⅔; 13, *Ambocœlia planoconvexa,* × 2; 14, *Composita subtilita,* × ⅔; 15, *Hustedia mormoni;* 16, *Dielasma bovidens;* 17, *Pseudomonotis hawni,* × ½; 18, *Myalina subquadrata,* × ½; 19, *Allorisma subquadratum,* × ½; 20, *Schizodus harii;* 21, *Leda bellistriata,* × 3; 22, *Euphemus carbonarius,* × 1½; 23, *Soleniscus fusiformis;* 24, *Worthenia tabulata;* 25, *Phillipsia major.*

Figure 433, Page 757

Figs. *A* and *B*, *Solenocheilus kentuckiense,* × ½; *C*, *Domatoceras militarium,* × ½; *D* and *F*, *Glyphioceras incisum,* × 2; *E* and *G*, *Waagenoceras cumminsi,* × ⅘.

From the Texas State Survey.

Plate 24, Page 765

Fig. 1, *Alethopteris grandifolia;* 2, *Neuropteris fasciculata;* 3, *N. capitata;* 4, *Pseudopecopteris mazonana;* 5, tree fern, *Megaphyton,* restored by Kidston; 6, *Sphenopteris mixta;* 7, *Archæopteris stricta;* 8, *Aneimites fertilis,* × 2; 9, same with a young seed, × 4; 10, same, with one of the seeds restored, × 3.

Figs. 1–7 from the Illinois and Ohio State Surveys; Figs. 8–10 after David White.

Plate 25, Page 767.

Fig. 1, restoration of the tree *Lepidodendron,* about × $\frac{1}{100}$; 2, leaf of the spore-bearing cone, about × ⅓, those of the branches are very similar but longer; 3, outer surface of tree, showing nature of leaf bases, about × ½ (*L. obovatum*); 4, spore-bearing cone (*Lepidostrobus*), with and without leaves, sectioned to show spores and spore-developing cases (sporangia); 5, bunch of four microspores; 6, macrospore; 7, two species of the tree *Sigillaria,* restored, about × $\frac{1}{50}$; 8, section through trunk, showing relative thicknesses of outer leaf-bearing layer, two zones of cork-like bark, comparatively thin internal cylinder of wood, and medial pith; 9, roots of these trees (*Stigmaria ficoides*), with rootlets and scars of their attachment.

Figs. 1–6 after Steinmann; Figs. 7 and 8 after Zittel.

Plate 26, Page 773

Fig. 1, Calamite trees restored, the one on the left bearing a spore case, about × $\frac{1}{100}$; 2, basal end of a Calamite; 3, Cordaite tree restored (*Dorycordaites*), about × $\frac{1}{100}$, also showing nature of catkin-like flowers; 4, different type of *Cordaites,* about × $\frac{1}{40}$; 5, *Trigonocarpon ornatum,* a fruit or seed of a Cordaite; 6, *Rhabdocarpus apiculatus,* seed of a Cordaite; 7, branchlet of the living maiden-hair tree (*Ginkgo biloba*), showing leaves, male flowers, and on the right the mature seed.

Figs. 1 and 2 after Zittel; Fig. 3 after Grand'Eury, from D. H. Scott; Fig. 4 after Dawson, from Le Conte; Figs. 5 and 6 after the Ohio State Survey; Fig. 7 after Steinmann.

PLATE 27, PAGE 799

Fig. 1, *Necturus maculatus* of the Ohio and Mississippi rivers; 2 and 3, *Siren lacertina*, a small salamander, note the three pairs of gills and the absence of hind legs; 4, *Amphiuma tridactyla*, with both gills and lungs; 5, *Trematops milleri*, a stegocephalian, 3 feet long, from Texas; 6, *Cacops aspidephorus*, a stegocephalian, 20 inches long, from Texas.

Figs. 1 and 4 from Parker and Haswell; Figs. 2 and 3 after Lankester, British Museum Guide Book; Figs. 5 and 6 after Williston.

PLATE 28, PAGE 805

Cotylosaurs:

Fig. 1, *Diasparactus zenos*, about 7 feet long, from New Mexico; 2, *Limnoscelis paludis*, about the same length and from the same state.

Pelycosaurs:

Fig. 3, *Varanosaurus brevirostris*, an agile form, nearly 4 feet long, from Texas; 4, *Casea broilii*, of about the same length and from the same state; 5, *Ophiacodon mirus*, about 7 feet long, from New Mexico; 6, *Dimetrodon*, about 8 feet long, from Texas.

All after Williston.

PLATE 30, PAGE 829

Fig. 1, *Pseudomonotis subcircularis*, $\times \frac{1}{2}$; 2, *Daonella dubia*, $\times \frac{1}{2}$; 3, *Atractites burckhardti*, $\times \frac{1}{3}$; 4 and 5, *Anolcites meeki*, $\times \frac{1}{2}$; 6 and 7, *Tropites subbullatus*, $\times \frac{1}{2}$; 8–10, *Joannites nevadanus*, $\times \frac{1}{2}$; 11 and 12, *Meekoceras gracilitatis*, $\times \frac{3}{4}$; 13 and 14, *Gymnotoceras russelli*, $\times \frac{3}{4}$; 15, *Tropigastrites rothpletzi;* 16, *Sageceras gabbi*, $\times \frac{1}{2}$.

After J. P. Smith, from the U. S. Geological Survey.

PLATE 31, PAGE 832

Footprints, $\times \frac{1}{12}$, of:

Fig. 1, *Anchisauripus* (*Brontozoum*) *sillimani;* 2, *Sauropus barrattii* (*Anomœpus major*); 3, *Gigandipus caudatus;* 4, *Eubrontes* (*Brontozoum*) *giganteus;* 5, *Otozoum moodii.*

Restorations, $\times \frac{1}{24}$, of carnivorous dinosaurs:

Fig. 6, *Anchisaurus colurus;* 7, *Podokesaurus holyokensis.*

Fig. 8, restoration, $\times \frac{1}{24}$, of the herbivorous ornithopod dinosaur *Sauropus barrattii;* 9, restoration, $\times \frac{1}{24}$, of the aëtosaur *Stegomus.*

All after Lull.

PLATE 32, PAGE 834

Sauropods:

Fig. 1, *Brontosaurus excelsus*, $\times \frac{1}{180}$; 2, *Diplodocus carnegiei*, $\times \frac{1}{180}$; 3, *Pleurocœlus nanus*, $\times \frac{1}{180}$.

Fig. 4, the predentate *Camptosaurus*, $\times \frac{1}{60}$; 5, the armored *Stegosaurus ungulatus*, $\times \frac{1}{60}$; 6, the bird-catching *Ornitholestes hermanni*, $\times \frac{1}{60}$.

All after Lull.

PLATE 33, PAGE 839

Fig. 1, horned dinosaur, *Triceratops prorsus;* 2, head of *T. clutus*, the culminating form of one line of Ceratopsia; 3, head of another culminating species, *Torosaurus gladius;* 4, older, much horned ceratopsian, *Styracosaurus albertensis;* 5, another older form, *Monoclonius flexus;* 6, bipedal predentate, *Trachodon* (*Claosaurus*) *annectens;* 7, the king tyrant carnivore, *Tyrannosaurus rex.*

All after Lull. About $\times \frac{1}{60}$.

Plate 37, Page 903

Fig. 1, *Terebratuia harlani*, × ⅔; 2, *Terebratella plicata;* 3, *Ostrea larva;* 4, *O. lugubris;* 5, *Exogyra costata*, × ½; 6, *Inoceramus vanuxemi*, × ½; 7, *Turritella whitei;* 8, *Admetopsis subfusiformis;* 9, *Cancellaria malachitensis;* 10, *Cryptorhytis utahensis;* 11, *Pyropsis bairdi*, × ½; 12, *Aporrhais prolabiata;* 13, *Scaphites nodosus*, × ½; 14, *Baculites compressus*, × 10; 15, fragment of an adult of same species, to show suture line; 16, *Heteroceras stevensoni*, × ½.

After Stanton, Whitfield, and Scott.

Figure 495, Page 905

Fig. *A*, *Scaphites hugardianus; B, Ancyloceras matheronianum* (Aptian), × ½; *C*, *Hamites rotundus* (Gault); *D*, *Ptychoceras puzosianum* (Neocomian); *E*, part of straight cone of *Baculites gaudini.*

All from Heer.

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